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ON THE PERMANENT EFFECTS OF STRAIN IN METALS; ON THEIR SELF-REGISTRATION, AND MUTUAL INTERACTIONS.

By ROBERT H. THURSTON, M. Am. Soc. C. E.

Some years since the writer was very much interested in the various phenomena illustrating a singular molecular habit of the metals, when subjected to stress exceeding their elastic limits, and which results in permanent deformation, all of which phenomena seemed to have important practical bearing upon the work of the engineer, and the safety and the life of his structures. A number of minor investigations were at that time made by him and recorded in the papers which may be found bearing his name in the *Transactions* of the American Society of Civil Engineers of that time.*

In a paper read December 6th, 1876, the writer gave an account of experimental investigations leading to the determination of the "rate of set of metals subjected to strain," and showing both an observed decrease of resistance at a fixed distortion, and an increase of deflection under a

* See *Transactions*, March and April, 1876; January, 1877; March, 1878; May, 1880.

fixed load. It was then shown that certain important modifications of the strength and ductility, and of the molecular characteristics, of metals were produced by modifications in method and time of loading, and it was shown both that the ultimate resistance might be increased by a long period of loading, and that a member loaded to a point far within its breaking limit, as indicated by ordinary test, might yet be fractured by the lesser load, if sufficiently long subjected to it. A marked difference in the behavior of iron and steel as compared with most of the alloys was observed, and it was concluded that they constitute a safer class than the latter. It was also concluded that the "iron-class" might be expected to carry indefinitely, at least far beyond the elastic limit, loads to which they had been found equal by test, however long the time of action. This latter conclusion has since been found to be less general than was then supposed, and experiments since made, and others in progress, indicate that this safety is limited to cases where the factor of safety is at least 1.5 and perhaps even 2.*

In a paper read before the same society, March 20th, 1878, a "new method of detecting overstrain" in metals of the "iron-class" was described and discussed, with an account of the experiments leading to its discovery, and with illustrations of some of its many important applications in practice. It was shown that "a metal, once overstrained, carries permanently unmistakable evidence of the fact, and can be made to reveal the amount of such overstrain at any later time with a fair degree of accuracy." It was shown that this evidence cannot be destroyed by any known method, even heating and annealing only obscuring without extinguishing it. The main fact of this case is that the elastic limit found by ordinary test, in any piece of iron or steel, is the record of the maximum stress to which it had at any time previously been subjected; whether by accident or in the process of manufacture. If low, and at the usual limit, it indicates the maximum stress exerted in the process of rolling or working into the final shape; if high, it is usually the result of some subsequent accident or otherwise produced overstrain. It was shown how this fact might perhaps be sometimes made useful in the discovery of the method and causes of the breaking down of bridges or of machinery.

In another paper, read April 7th, 1880, the writer showed the fact of

* Iron and Steel; Vol. II; Materials of Engineering; R. H. Thurston, especially Chapter X, Article 295.

the production of changes of molecular condition and of stress and strain in all directions by the action of any force appreciably straining the piece, and acting in any one direction, whatever that direction might be; resistances being increased to all directions of strain by strain in any one direction. This "variation of the resistance due to orthogonal strain," and variation of the elastic limit in every direction by such straining, was described as revealed by the researches of the writer, and some of its more important applications were suggested and their value indicated. "Iron and steel rods broken by tension were found to have their transverse elastic limits abnormally elevated, and to have become very stiff and of comparatively slight ductility." Lateral compression, as by cold-rolling, produced "great increase of strength and stiffness, and an even more considerable exaltation of the normal elastic limit. Torsion similarly stiffened wires and rods longitudinally; and test-pieces longitudinally strained became stiffer against torsionally and transversely applied stress." It was concluded that "thus orthogonal strains mutually affect orthogonal resistances of metals; and the engineer is by this fact compelled to study these mutual influences in designing structures in which the stresses approach, or may exceed, separately or in combination, the normal primitive elastic limit of his material." Many illustrations of such phenomena were described and illustrated by the figures obtained by test, and by the curves produced by plotting the results given and tabulated.

The principle thus revealed, and which is likely to prove of such importance to the engineer, may be enunciated thus:

If a metal be subjected to a stress of any given kind, or in any stated "sense," sufficient to produce permanent strain and set, then its ultimate resistance to that, or to any other kind of stress, will be sensibly increased, and in all directions, whatever the line of action of the deforming stress.

Mr. George W. Bissell, in charge of the work of instruction in the Sibley College laboratories, has illustrated this principle by the following series of striking and suggestive experiments:

Four series of experiments were planned, in each of which the material employed was subjected to strain in either tension, compression, torsion, or by transverse loading; and the application of another straining force was then made to reveal the permanent effect of the first, and the altered elastic limit and ultimate resistance.

For convenience the several series have been designated as *A*, *B*, *C*, *D*; and the specimens have been numbered consecutively from 1 to 16.

The material used in all of the tests was machinery steel (0.5 *C*).

(1.) SERIES A.—Four test-pieces, ¾ inch diameter, 14 inches long, were prepared by turning in each at the middle of its length a neck, ½ inch diameter and 2 inches long. One piece was tested by tension until a decided set was obtained. A second piece was bent in the neck, straightened and then bent and straightened again in a plane at right angles to that of the first bending.

A third piece was twisted forward and back between the centers of a lathe (the ends being dogged to the face plate and tail-stock, power being applied by the driving belt twisted the specimen). The fourth piece was compressed until decidedly bulged in the neck.

This neck served in all cases to localize the stress.

The four specimens were then turned to an accurately uniform diameter, somewhat less than that of the previously strained part, for a length of 10 inches. Finally the four pieces were pulled in the testing machine until a decided neck was formed.

It was then observed (see Nos. 1–4) that the previously strained portion was, in each case, of greater diameter by a visible amount than any other part of the specimen, the "neck" having formed near one end; thus showing increased resistance to tension in the strained section and decreased ductility. (See Plate XIV.)

Below are tabulated in thousandths of an inch the diameters of various parts of the several test-pieces :

SERIES A.

No.	Diameter At		
	One and a half inch Left of Middle.	Middle of Strained Section.	One and a half inch Right of Middle.
1	479	526	475
2	452	477	449
3	474	486	465
4	500	524	495

PLATE XIV.
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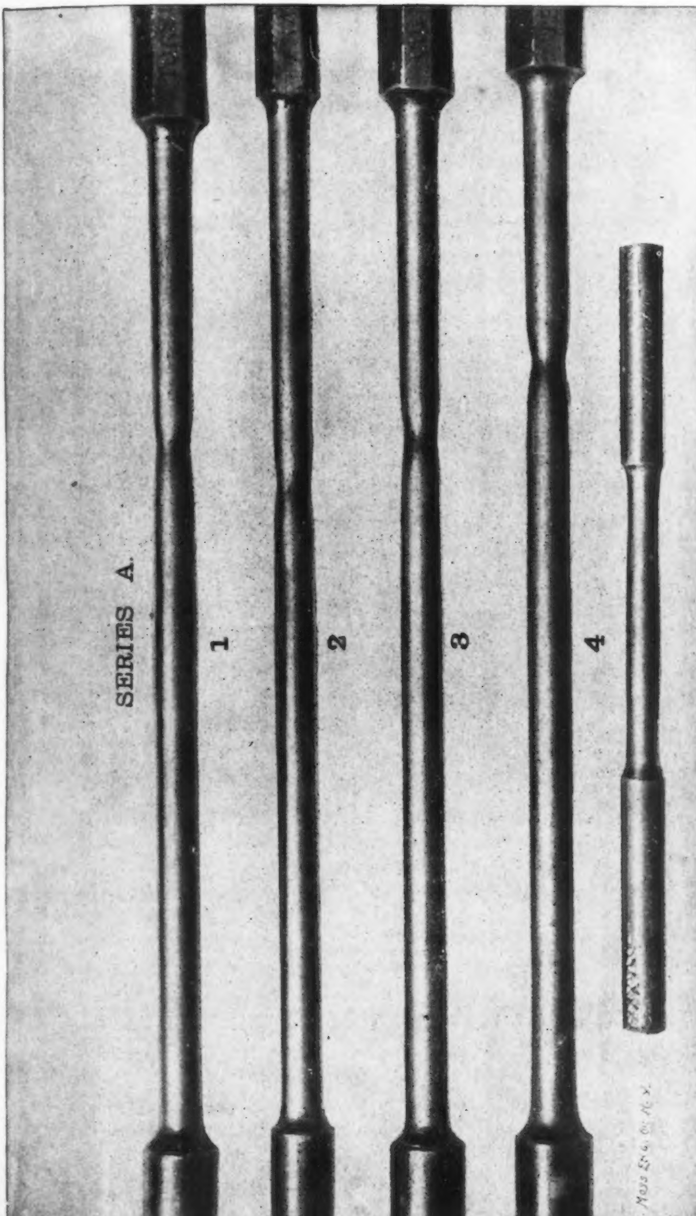

(2.) SERIES B.—Five torsion test-pieces were used. One was turned to standard size and broken in the Thurston "Autographic" machine, a diagram being taken.

Another was made with extra long shanks and turned down at its middle to $\frac{3}{4}$ inch diameter and $\frac{3}{8}$ inch between shoulders. This piece was strained by tension until a decided set was noticeable. The three remaining pieces were reduced at the middle by turning to $\frac{3}{4}$ inch diameter and $\frac{3}{8}$ inch long, and were subjected one each to severe compressive, torsional and transverse stresses, in each case obtaining a permanent set.

The four specimens were then converted into standard torsion test-pieces and were tested to rupture by torsion, diagrams being obtained on same sheet with the first set from the same specimens. The curves showed increased resistance and decreased ductility, and the specimens, when etched to show the disposition of the fibers, displayed on each helices of different pitch; the more oblique being upon the parts strained but once and the less inclined upon the maltreated portion. The pitch being proportional to ductility, we see at once the effect of maltreatment upon this property of the material. (Plate XV.)

The phenomenon is most marked in Nos. 7 and 5, which were originally strained by compression and flexure respectively, but is nevertheless apparent in the other cases upon the specimens themselves.

(3.) SERIES C.—Four pieces, 4 inches long by $\frac{5}{8}$ inch diameter, were prepared by turning each near the middle section to a diameter of $\frac{7}{16}$ inch for a length of $\frac{3}{16}$ inch. These pieces were strained severely by tensile, compressive, torsional and transverse stresses respectively, and from each was cut a compression test-piece, $\frac{3}{4}$ inch long by $\frac{3}{8}$ inch diameter, in such a way as to bring the maltreated portion in the middle of its length. These were finally subjected to high compressive stress and with the same interesting effect in all (Nos. 9–12), viz., much larger diameter at the ends than at the middle section. The pieces tended to assume an hour-glass shape. (Plate XV.)

This result indicates increased strength and decreased ductility in the maltreated parts.

(4.) SERIES D.—Four bars, 8 inches long by $\frac{5}{8}$ inch diameter, were centered, and in each was turned a neck, 1 inch long by $\frac{7}{16}$ inch diameter; the same being located wholly to one side of the middle, *i. e.*, 4 inches from one end and 3 inches from the other.

The several bars were then subjected to the four kinds of stress, the same being, as before, sufficient to give permanent set. Then they were turned down to about $\frac{5}{16}$ inch diameter over the whole length and subjected to transverse stress applied at the middle, which was also the middle of the supported length of 6 inches. As the force was applied the bar was seen to bend almost entirely on that side of the middle which had not been treated. In one or two cases the previously strained half was perfectly straight (Nos. 13-16). In the figures the points of application of the force and of support are indicated.

Thus, by a series of "qualitative" tests, the results of which are visible to the unaided eye, the proposition was demonstrated.

It was desired to make this set of specimens more complete by adding a similar set obtained by similar experiments upon other metals than iron, but owing to the commonly accepted theory of the effect of time stresses on the brasses, it has not until lately been thought probable that the above experiments could be repeated upon brass with satisfactory results. However, while preparing this paper, an experiment upon a piece of brass was made by Mr. Bissell according to the method indicated in Series A, and the result is shown in the photograph of the specimen (No. 4, Plate XIV).

The conclusion is, obviously, that it may be possible to detect in brass a behavior similar to that of iron in this respect, which is what might be expected if strains caused by wire-drawing can be modified, if not removed, in both classes of metals by annealing.

This latter discovery thus made by Mr. Bissell will probably be considered of sufficient importance to justify its publication in this manner.

DISCUSSION.

J. B. Johnson, M. Am. Soc. C. E.—Such facts as are presented here do not strike me as being particularly new, but they are none the less important for that. It has been well known, it seems to me, to all investigators in metals, that cold working of any kind increases the strength of the metal to a material extent. I have shown myself, that cold drawing of 50 000 pounds iron, up to 45 000 pounds or up to rupture, giving it a period of rest and testing again, will increase the strength of the iron to about 70 000 pounds; and these facts are given in the standard publications, as well as in Society papers. The strength, however,

PLATE XV.
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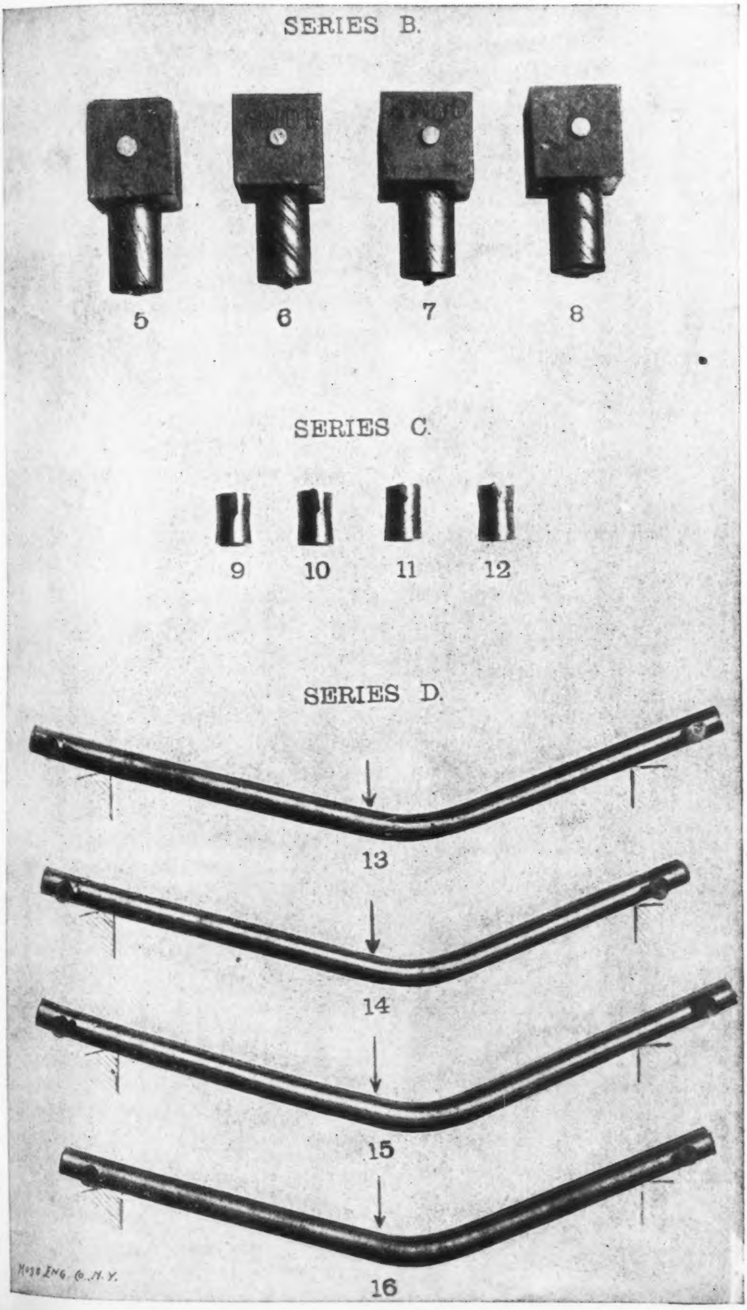


increases with the time of rest. If 50 000 pounds iron be tested to rupture, and a broken end of the same piece be broken again after one day, it will run probably to 58 000 pounds; if it be broken in one week it will go to over 60 000 pounds; if broken in three weeks it will probably break at about 62 000 pounds, so there is a time effect;* what the nature of this effect is, would be a very interesting subject for study. We know, too, that the effect of cold bending would be to increase the strength. When you take a piece of soft wire and try to break it by bending, you bend it one way and try to bend it back again, it bends somewhere else. So you take a piece of soft iron wire and pull it or stretch it away beyond its elastic limit, and it strengthens it. It seems to me we have observed the same effect in the bending of tin; it is very difficult to straighten bent tin, it bends back in another place and you get another bend; this illustrates almost as well as any other experiment, that the character of the material, at that point, has been changed. Pulling a piece of iron in the testing machine is nothing more or less than a process of wire drawing. If you put it in a compression machine and crush it beyond its elastic limit, it is nothing more or less than cold rolling. So that all these facts, it seems to me, are well known in certain ways, while they may not have been granted by every one as general principles. Engineers will usually say, when engineering materials have been tested beyond their elastic limits, they are injured and must not be used, or, that iron which has been strained beyond its elastic limit must no longer be used. It is important that these points should be discussed. Inasmuch as these are facts, and universal facts, why should engineers insist constantly that when a piece of iron has been strained beyond its elastic limit it has been permanently injured? We do not think wire is a dangerous material to work with; we think iron or steel wire a very good material to build structures from, and no one hesitates to endorse the Brooklyn Bridge because it is built of wire; all that wire has been stretched away beyond its elastic limit. We do not know what the elastic limit of steel which is rolled at an unknown heat is, the colder it is the higher that limit. If a piece of 50 000 pounds iron be stretched to 45 000 pounds, then 45 000 pounds is its elastic limit; for all practical purposes we call it perfectly elastic up to the limit of its previous loading. It makes the product rather more certain in its qualities and more readily determined, and rather more constant; and its strength, as in iron, may be increased 20 per cent. Therefore I would like to know why we should continue to insist that a material is injured when it is strained beyond its elastic limit.

F. W. Skinner, M. Am. Soc. C. E.—There are one or two points that suggest themselves to me, from Professor Johnson's remarks with regard to the benefit of straining metal beyond its elastic limit, and the advisa-

* See paper by the writer before Engineer's Club, St. Louis, in Jour. Assoc'n Eng. Soc's, Vol. VII, 1887, p. 98, giving experiments.

bility of afterward using it. Most of us are familiar with the experiments relating to the destruction of metal by the repeated application of the same strain. It is agreed that it endures an unlimited number of strains, if they are restricted to a district considerably below the elastic limit; whereas a much less number of applications nearer to, or above that point, and below its original breaking load, will destroy the metal. I think that this is a very important consideration in designing all our structures.

With regard to the improvement of metal by a strain beyond the elastic limit, Professor Johnson instances wire. I think there can be no doubt he is right about that, but I do not see how it is applicable to any structure that we have to deal with. Elementary members, much less girders, trusses, etc., cannot be commercially strained up to the elastic limit by any machines now in existence before they are put in the structure; if, afterward, when the structure is completed, they are tested to any such degree as that, they by the very definition of elastic limit—as the point where permanent set begins—would suffer irremediable distortion, causing or hastening destruction. I think that that would preclude the application of this principle in this case. Then, again, when we strain structural material beyond the elastic limit, we develop and increase latent flaws which are not apparent or are insignificant, and which might not otherwise amount to anything, and make, possibly, slight imperfections to become a great danger, though still concealed.

Professor JOHNSON.—I do not want to go on record as recommending working structures up to or beyond their elastic limits, it was only the question of a single stress beyond the elastic limit injuring the material. I would not for a moment recommend using any higher stresses than good practice now endorses. Take a chain, for instance; I believe that a chain when tested for strength, is benefited if it is pulled out beyond its elastic limit. It is then in a condition of perfect elasticity up to the load we have used. We have, of course, taken out of that material a certain amount of its total resilience. We have probably diminished its capacity for repetition of load; that is, if it is going to be worked till it fails at repeated heavy loads, it probably will not do as much work after we have stretched it beyond the elastic limit as it would have done in the beginning. It is simply a question whether engineers ought to be a little nervous about using a material for nearly static loads, which has been strained beyond its elastic limit.

Mr. SKINNER.—Do you refer to steel as well as iron?

Professor JOHNSON.—Yes.

Professor H. T. EDDY.—It seems to me that Professor Thurston has called attention in this paper to a matter of great interest to us all, viz., to the manner in which metal is affected in several directions by a strain in any single direction.

If, for example, we roll or hammer a piece of iron, cold or hot, we

thereby squeeze it out sidewise, and elongate it in directions at right angles to the force applied by the rolls, and its moduli of elasticity as well as its ultimate strength in these directions have been changed by the process. The value of this paper lies in the fact that by a series of carefully devised experiments, Professor Thurston has clearly demonstrated the actual existence of what has too often been regarded as a theoretical abstraction which might be safely neglected by the practical man.

In view of this, permit me to review the fundamental theoretical relations existing between deformations and the forces producing them, or, in more precise language, the theory of stresses and strains. The method by which the equations expressing the relations between the stresses and strains in an elastic solid are established in most of our text-books, although it has been employed by almost all the more important writers upon this subject, such as Poisson, Navier, Lamé and others, is, nevertheless one which has in it obscurities that constantly lead to doubt and erroneous conclusions, respecting the behavior and actual properties of elastic material subject to stress.

The labors of Stokes, and of Thomson and Tait, have put the fundamental conceptions which furnish the basis of these equations in a new and clearer light. This new method of establishing these relations seems not yet to have attracted the attention of engineering writers. It shall, therefore, be the object of this discussion to give an exposition of the subject, which, without following closely any previous presentation, shall nevertheless embody the improved method, and be drawn out in such detail as to give a clear insight into this theory, upon which accurate conceptions are of importance in designing engineering structures.

Every solid, whether perfectly or imperfectly elastic, necessarily exhibits two distinct kinds of resistance to deformation. In the first place, it offers resistance to change of volume. Fluids as well as solids offer resistance to compression, *i. e.*, diminution of volume, but solids resist dilatation also, and in such a way that the proportionate change of volume within elastic limits, is almost exactly the same for dilatation as for compression. The cubic compressibility of wrought-iron is seventy or eighty times as great as water. A piece of iron or other material can be subjected to this kind of stress by being put under hydraulic pressure in a fluid.

A second kind of resistance to deformation, called rigidity, is developed when forces are applied which tend to make one part of a solid slide on that beside it.

Perfect fluids have no rigidity, and offer no resistance to forces applied in this manner. Viscous fluids are somewhat rigid, at least for rapid changes, but do not recover their shape when distorted in this way. Force distributed over a surface in such a way as to tend to make one part slide on the other, is a shearing force or shearing stress, and the slight elastic displacement which takes place is a shearing strain. The

rigidity of the various elastic solids, differs greatly. India-rubber, for example, has little rigidity compared with most solids, the rigidity of iron is many hundred times as great, but the cubic compressibility of India-rubber is nearly the same as water.

The physical character of an elastic solid, so far as concerns its elastic properties, is completely determined by its behavior under these two kinds of stress. It has been assumed by some, that these two kinds of elasticity have a fixed relation to each other which is the same for all bodies, or at least for all metals; but such is evidently not the case; for, as has been stated, the compressibility of iron exceeds that of rubber many times, while the amount which iron will yield to a shearing stress is an exceedingly small fraction of the yielding observed in rubber.

When a solid is subjected to direct compression under hydraulic pressure, it may be such on the one hand, that every straight line which is supposed to be drawn in the solid is shortened in the same ratio, or, on the other hand, it may be that the solid is more compressible in some directions than in others. This last kind of structure or texture, may be thought to be especially the case with crystalline bodies. So, too, the rigidity of a body may be different in different directions. For the present, only those bodies will be treated which are alike in all directions; such bodies are called *isotropic*, to denote this property.

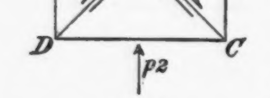


FIG. 1.

In order to comprehend how an elastic solid is deformed by forces applied in the usual manner, *i. e.*, in certain given directions, it is necessary to show how a simple tension or compression in a single direction, can be replaced by an equivalent system of stresses consisting only of hydraulic pressures, positive or negative, and shearing stresses. To this let us now proceed. For convenience, let the stress of the first kind, which consists of a uniform pressure or tension in all directions, be called a solid stress, and be regarded as positive in case it produces tension, and negative in case of compression, so that ordinary hydraulic pressure is negative.

It is to be noticed that in a shearing stress the forces acting are all parallel to one plane, and so it is a plane stress, and would act as does a couple, to turn the body about an axis perpendicular to the plane of the stress, were it not held in equilibrium. The only way it can be thus held in equilibrium without affecting its own intensity, is by another shearing stress parallel to the same plane and of equal intensity, tending to turn the body in the opposite direction, but distributing over planes at right angles to the first-mentioned shearing stress.

The relations of these two shearing stresses in equilibrium is shown

in Fig. 1 as acting along the diagonal planes of the cube $A\ B\ C\ D$, forming part of the interior of the solid.

Suppose the intensity of the shearing stress in each diagonal is p per square unit, and consider the forces acting upon the prism $O\ B\ C$ which is one quarter of the cube.

In order that $O\ B\ C$ may be in equilibrium, a normal stress p_1 must act on $B\ C$ of an intensity equal to p; for the total force parallel to $A\ B$ on the faces $O\ B$ and $O\ C$ is $(O\ B + O\ C)\ \frac{p}{\sqrt{2}} = B\ C\,p$, which force must be balanced by $B\ C\ p_1$ acting on $B\ C$. $\therefore p_1 = p$. Similarly it may be shown that a normal stress $p_2 = -p$ must act on $A\ B$. In other words, the state of stress induced at any point of the solid by the action of a pair of shearing stresses in planes at right angles, is equivalent to a compression and a tension of the same intensity, applied to planes bisecting the angles between the planes of shear; or *vice versa*, a tension and a compression of equal intensity on planes at right angles, is equivalent to a shearing stress of the same intensity on each of the planes bisecting the angles between the planes at right angles.

Again, let us consider a portion of an elastic solid in the form of a cube whose edges are parallel to a system of rectangular axes x, y, z. Let a uniformly distributed stress of intensity p_1 act parallel to x in opposite directions, on the two faces perpendicular to x; and let p_1 be positive for tension, negative for compression.

The stress p_1 may be regarded as compounded of a uniform solid stress of intensity $\frac{1}{3}\,p_1$ on each of its six faces, together with two shearing stresses, as follows: One consisting of a stress of $\frac{1}{3}\,p_1$ along x and $-\frac{1}{3}\,p_1$ along y, the other of a stress of $\frac{1}{3}\,p_1$ along x and $-\frac{1}{3}\,p_1$ along z. This separation of the simple stress p_1 along x into component parts which are together equal to p_1 may be exhibited for convenience in tabular form, thus:

		1	2	3
Stress along....................	$x =$	$\frac{1}{3}\,p_1$	$+\ \frac{1}{3}\,p_1$	$+\ \frac{1}{3}\,p_1$
" "	$y =$	$\frac{1}{3}\,p_1$	$-\ \frac{1}{3}\,p_1$	$+\ O$
" "	$z =$	$\frac{1}{3}\,p_1$	$+\ O$	$-\ \frac{1}{3}\,p_1$

The stress in column 1 of this table is a solid stress; that in column 2 is a shearing stress whose planes of shear are the diagonal planes of the cube which mutually intersect in the axis of z, and so bisect the angles between the remaining axis x and y. A similar statement holds respecting column 3.

Again, if p_2 act along y, it can be separated into three component states of stress, as shown in the following table:

		4	5	6
Stress along....................	$y =$	$\frac{1}{3} p_2$	$+ \frac{1}{3} p_2$	$+ \frac{1}{3} p_2$
" "	$z =$	$\frac{1}{3} p_2$	$- \frac{1}{3} p_2$	$+ O$
" "	$x =$	$\frac{1}{3} p_2$	$+ O$	$- \frac{1}{3} p_2$

The stresses in this table form one solid stress and two shearing stresses, as in the previous table.

And, if p_3 act along z, it may also be separated into a solid stress and two shearing stresses, thus:

		7	8	9
Stress along....................	$z =$	$\frac{1}{3} p_3$	$+ \frac{1}{3} p_3$	$+ \frac{1}{3} p_3$
" "	$x =$	$\frac{1}{3} p_3$	$- \frac{1}{3} p_3$	$+ O$
" "	$y =$	$\frac{1}{3} p_3$	$+ O$	$- \frac{1}{3} p_3$

Let m be the co-efficient of elongation, *i. e.*, m is the intensity of a solid stress divided by the linear strain it produces. The value of m is numerically equal to the intensity of a solid stress, under whose action each edge of a unit cube would be elongated a unit, in case it could be so elongated, without passing the limits of elasticity. Hence, the elongation due to the solid stress $\frac{1}{3} p_1$ is $p_1 \div 3\, m$.

Also, let n be the co-efficient of shearing strain measured by the amount by which two parallel planes, at the distance of one unit apart, are displaced by the sliding effect of a shearing stress, *i. e.*, n is the intensity of a shearing stress divided by the shearing strain produced by it, and it is numerically equal to the intensity of the shearing stress which would cause a displacement of unity in two parallel planes one unit apart, provided the limits of elasticity were not passed in so doing. The values of m and n must be determined experimentally for any given material. It is evident that they serve to measure respectively the elasticity of volume, and the rigidity of the material.

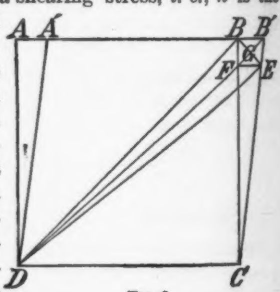


FIG. 2.

That we may obtain the relation between amount of shearing strain n and the amount of the elongation and contraction in the planes bisecting the angles between the planes of shear, let the unit cube $A\ B\ C\ D$ be infinitesimally distorted by a shearing stress of intensity p, acting on the parallel planes $A\ B$ and $C\ D$, accompanied by a shearing stress of equal intensity on the planes $A\ D$ and $B\ C$, such that they together are in equilibrium.

Let the shearing strain be $A A'$, then

$$\frac{A A'}{A D} = \frac{B B'}{A D} = \frac{p}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The shearing stress p is equivalent to a compression of intensity p along $A C$, and a tension of intensity, p, along $B D$. To find the elongation per unit in the diagonal $B D$, let $B' D$ cut $B C$ in F. Complete the infinitestimal square $B F E B'$. Now $A B$: $B B'$: $D B$: $F B'$ ($= 2 G F$), the total elongation is $\frac{1}{2} F B' = B' G = G F$. Hence, the elongation per unit is

$$\frac{G F}{D B} = \frac{\frac{1}{2} B B'}{A B} = \frac{p}{2n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The contraction occurring in $A C$ is of equal amount. Hence it appears geometrically that the elongation and the contraction per unit of length in the directions of the tension and the compression, which are equivalent to a shearing stress, is numerically one-half as great as the displacement of planes of shear one unit apart. On applying this conclusion to find the strain produced by the stresses in column 2 of the first table, which have an intensity of $\frac{1}{3} p_1$ along x and $-\frac{1}{3} p$ along y, it appears that they produce an elongation of $\frac{p_1}{6n}$ along x and $-\frac{p_1}{6n}$ along y. The stresses in column 3 act in a similar manner.

It thus appears that we may exhibit the elongations due to the component stresses into which p_1 has been separated, in the following tabular form:

		1		2		3
Strain along	$x =$	$\frac{p_1}{3m}$	$+$	$\frac{p_1}{6n}$	$+$	$\frac{p_1}{6n}$
" "	$y =$	$\frac{p_1}{3m}$	$-$	$\frac{p_1}{6n}$	$+$	0
" "	$z =$	$\frac{p_1}{3m}$	$+$	0	$-$	$\frac{p_1}{6n}$

Similarly the component strains into which p_2 has been separated produces strains tabulated as follows:

		4		5		6
Strain along	$y =$	$\frac{p_2}{3m}$	$+$	$\frac{p_2}{6n}$	$+$	$\frac{p_2}{6n}$
" "	$z =$	$\frac{p_2}{3\,m}$	$-$	$\frac{p_2}{6n}$	$+$	$\frac{p_2}{0}$
" "	$x =$	$\frac{p_2}{3m}$	$+$	0	$-$	$\frac{p_2}{6n}$

In like manner the components of p_3 cause the strains:

		7		8		9
Strain along...............	$z=$	$\frac{p_3}{3m}$	$+$	$\frac{p_3}{6n}$	$+$	$\frac{p_3}{6n}$
" "	$x=$	$\frac{p_3}{3m}$	$-$	$\frac{p_3}{6n}$	$+$	0
" "	$y=$	$\frac{p_3}{3m}$	$+$	0	$-$	$\frac{p_3}{6n}$

Denote the total elongation along x, y, z, due to the combined action of p_1, p_2, p_3 by l_1, l_2, l_3, respectively; then is the total elongation in either of these directions found, by taking the algebraic sum of the elongations due to each of the stresses p_1, p_2, p_3, as given in the foregoing tables; hence,

$$\left.\begin{aligned} l_1 &= \frac{1}{3}\left(\frac{1}{n}+\frac{1}{m}\right)p_1 - \frac{1}{3}\left(\frac{1}{2n}-\frac{1}{m}\right)(p_2+p_3) \\ l_2 &= \frac{1}{3}\left(\frac{1}{n}+\frac{1}{m}\right)p_2 - \frac{1}{3}\left(\frac{1}{2n}-\frac{1}{m}\right)(p_3+p_1) \\ l_3 &= \frac{1}{3}\left(\frac{1}{n}+\frac{1}{m}\right)p_3 - \frac{1}{3}\left(\frac{1}{2n}-\frac{1}{m}\right)(p_1+p_2) \end{aligned}\right\}\ldots\ldots(3)$$

These equations, expressing the elongations per unit of length x, y, z respectively, due to the action of p_1, p_2, p_3, are thus arranged in a form which exhibits separately the co-efficients of p_1, p_2, p_3. The first co-efficient shows how much effect a stress has in producing elongation in its own direction, and is often denoted by

$$\frac{1}{E} \therefore \frac{1}{3}\left(\frac{1}{n}+\frac{1}{m}\right) = \frac{1}{E}\ldots\ldots\ldots\ldots\ldots(4)$$

The second co-efficient shows how much effect a stress has in producing contraction in directions at right angles to itself, and it may be taken as some fraction k of the first co-efficient, thus:

$$\frac{1}{3}\left(\frac{1}{2n}-\frac{1}{m}\right) = \frac{k}{E}\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

By (4) and (5), it is easy to express either of the four quantities m, n, k, E, in terms of two others; thus we find

$$\left.\begin{aligned} \frac{1}{m} &= \frac{3}{E} - \frac{1}{n} = \frac{1-2k}{E} = \frac{1-2k}{2n\,(1+k)} \\ \frac{1}{n} &= \frac{3}{E} - \frac{1}{m} = \frac{2\,(1+k)}{E} = \frac{2\,(1+k)}{m\,(1-2k)} \\ E &= \frac{3mn}{m+n} = m\,(1-2k) = 2n\,(1+k) \\ k &= \frac{m-2n}{m+n} = \frac{m-E}{2m} = \frac{E-2n}{2n} \end{aligned}\right\}\ldots\ldots(6)$$

By the help of (4) and (5), equations (3) may be written in the form:

$$\left.\begin{aligned} E\,l_1 &= p_1 - k\,(p_2 + p_3) \\ E\,l_2 &= p_2 - k\,(p_3 + p_1) \\ E\,l_3 &= p_3 - k\,(p_1 + p_2) \end{aligned}\right\} \dots\dots\dots\dots\dots\dots (7)$$

Equations (3) can be arranged in various ways by expressing the constants in terms of either two of the quantities m, n, k, E. If we take for brevity $p_1 + p_2 + p_3 = q$, then (3) may, for example, be put in the following form:

$$\left.\begin{aligned} l_1 &= \frac{p_1}{2n} - \tfrac{1}{3}\left(\frac{1}{2n} - \frac{1}{m}\right) q \\ l_2 &= \frac{p^2}{2n} - \tfrac{1}{3}\left(\frac{1}{2n} - \frac{1}{m}\right) q \\ l_3 &= \frac{p_3}{2n} - \tfrac{1}{3}\left(\frac{1}{2n} - \frac{1}{m}\right) q \end{aligned}\right\} \dots\dots\dots\dots (3a)$$

But equations (7) are of especial importance by the reason of the fact that the co-efficient E, which is known as "Young's Modulus of Elasticity," expresses the ratio of stress to strain in a piece subjected to direct tension or compression alone (*i. e.*, the lateral stresses vanish); while k is "Poisson's ratio," whose value may readily be seen to lie between the limiting values O and $\frac{1}{2}$; for, in case of perfect rigidity there is no lateral contraction, hence by definition $k = O$, while in case of perfect incompressibility, any longitudinal deformation must give rise to a total lateral deformation of one-half the amount in each of two directions, so that the total volume is unchanged, *i. e.*, $k = \frac{1}{2}$. But these constitute the two limiting cases between which all solids lie.

$$\therefore \tfrac{1}{2} > k > O.$$

Numberless experimental determinations of the value of E have been made within elastic limits, especially for iron and steel, so that its value is well known for the ordinary grades of material used in construction. There have been, however, but few determinations of the value of k for such materials. It has been frequently assumed by theorists that the value of k must be $\frac{1}{4}$ for all elastic solids. Experiment, however, does not show this to be the fact.

The following are the only trustworthy results of experiment known to me as to the substances named:

Wertheim	found	for	iron		$k = 0.317$
Maxwell	"	"	"		$k = 0.267$
Wertheim	"	"	mild steel		$k = 0.310$
Okatow	"	"	"	"	$k = 0.304$
Schneebeli	"	"	"	"	$k = 0.306$
Kirchhoff	"	"	hard steel		$k = 0.294$
Okatow	"	"	"	"	$k = 0.294$
Schneebeli	"	"	"	"	$k = 0.296$

The following table contains the ratios of m, n and E for several assumed values of k computed from (6), in which the number in the last column is the product of those in the two preceding columns:

k	$\frac{m}{E}$	$\frac{E}{n}$	$\frac{m}{n}$
0	1	2	2
$\frac{1}{4}$	2	2.5	5
$\frac{3}{10}$	2.5	2.6	6.5
$\frac{1}{3}$	3	$2\frac{2}{3}$	8
$\frac{1}{2}$	inf.	3	inf.

As before stated, it has been frequently assumed by theorists that k must be one-quarter for all elastic solids.

The set of linear equations (3) or (7) can be readily solved so as to express the values of p_1, p_2, p_3, each in terms of l_1, l_2, l_3. Instead of thus obtaining the stresses in terms of the strains, let us obtain them *de novo.*

A simple elongation along x can be regarded as composed of: 1st, a uniform dilatation of volume which elongates each edge of a unit cube parallel to each of the axes x, y, z, by the amount $\frac{1}{3}\, l_1$; 2d, a shearing strain producing an elongation of $+\frac{1}{3}\, l_1$, along x and of $-\frac{1}{3}\, l_1$, along y; 3d, a shearing strain producing an elongation of $+\frac{1}{3}\, l_1$, along x and of $-\frac{1}{3}\, l_1$, along z. Similarly, the elongation l_2 along y, and l_3 along z, can each be separated into three states of strain; in a manner precisely analogous to the separation of the stresses p_1, p_2, p_3, into component stresses in the first three tables given previously. If the word strain be substituted for stress, and l_1, l_2, l_3 be written for p_1, p_2, p_3, respectively, in those tables, we shall have a complete statement of the component states of strain. To produce these systems of strain there must be applied the states of stress exhibited in the following three tables, which are strictly analogous to the second set of three tables previously given, viz.:

		1	2	3
Stress along................	$x =$	$\frac{1}{3}\, m\, l_1$	$+\frac{2}{3}\, n\, l_1$	$+\frac{2}{3}\, n\, l_1$
" "	$y =$	$\frac{1}{3}\, m\, l_1$	$-\frac{2}{3}\, n\, l_1$	$+\,O$
" "	$z =$	$\frac{1}{3}\, m\, l_1$	$+\,O$	$-\frac{2}{3}\, n\, l_1$
		4	5	6
Stress along................	$y =$	$\frac{1}{3}\, m\, l_2$	$+\frac{2}{3}\, n\, l_2$	$+\frac{2}{3}\, n\, l_2$
" "	$z =$	$\frac{1}{3}\, m\, l_2$	$-\frac{2}{3}\, n\, l_2$	$+\,O$
" "	$x =$	$\frac{1}{3}\, m\, l_2$	$+\,O$	$-\frac{2}{3}\, n\, l_2$
		7	8	9
Stress along.................	$z =$	$\frac{1}{3}\, m\, l_3$	$+\frac{2}{3}\, n\, l_3$	$+\frac{2}{3}\, n\, l_3$
"	$x =$	$\frac{1}{3}\, m\, l_3$	$-\frac{2}{3}\, n\, l_3$	$+\,O$
"	$y =$	$\frac{1}{3}\, m\, l_3$	$+\,O$	$-\frac{2}{3}\, n\, l_3$

The total stresses p_1, p_2, p_3, along the axes x, y, z, respectively, are found by taking the algebraic sum of all the stress acting in each of these directions; hence,

$$\left.\begin{aligned} p_1 &= \tfrac{1}{3}(m+4n)\,l_1 + \tfrac{1}{3}(m-2n)(l_2+l_3) \\ p_2 &= \tfrac{1}{3}(m+4n)\,l_2 + \tfrac{1}{3}(m-2n)(l_3+l_1) \\ p_3 &= \tfrac{1}{3}(m+4n)\,l_3 + \tfrac{1}{3}(m-2n)(l_1+l_2) \end{aligned}\right\} \dots\dots\dots (8)$$

If $l_1 + l_2 + l_3 = v$, then v is the amount of the cubic dilatation and equations (8) may be written:

$$\left.\begin{aligned} p_1 &= 2n\,l_1 + \tfrac{1}{3}(m-2n)\,v \\ p_2 &= 2n\,l_2 + \tfrac{1}{3}(m-2n)\,v \\ p_3 &= 2n\,l_3 + \tfrac{1}{3}(m-2n)\,v \end{aligned}\right\} \dots\dots\dots\dots\dots\dots (9)$$

If it is desired to write the contents of equation (8) in terms of E and k instead of m and n, these become by (6):

$$\left.\begin{aligned} p_1 &= E\,\frac{(1-k)\,l_1 + k\,(l_2+l_3)}{(1+k)(1-2k)} \\ p_2 &= E\,\frac{(1-k)\,l_2 + k\,(l_3+l_1)}{(1+k)(1-2k)} \\ p_3 &= E\,\frac{(1-k)\,l_3 + k\,(l_1+l_2)}{(1+k)(1-2k)} \end{aligned}\right\} \dots\dots\dots\dots (10)$$

Equations (9) may also be expressed in simple form in terms of k and n, thus:

$$\left.\begin{aligned} p_1 &= 2n\left(l_1 + \frac{k\,v}{1-2k}\right) \\ p_2 &= 2n\left(l_2 + \frac{k\,v}{1-2k}\right) \\ p_3 &= 2n\left(l_3 + \frac{k\,v}{1-2k}\right) \end{aligned}\right\} \dots\dots\dots\dots\dots\dots (11)$$

It appears from these equations that a stress in any direction produces deformations at right angles to it, and that deformation in any single direction, not accompanied by deformations in directions at right angles to it can only occur in general under the action of lateral stresses together with stress in the direction of the deformation. This statement is true whether the deformation is one which does or does not exceed the elastic limits of the material. In case it is beyond the elastic limits, the co-efficients E, k, m and n are not constant, as they are within elastic limits, and will have, consequently, different values for different states of strain. From this it follows that Professor Thurston's admirable experiments establish the existence of the effects mentioned, to which no definite numerical values can from the nature of the case be assigned.

F. Collingwood, M. Am. Soc. C. E.—Professor Johnson has mentioned the use of wire for bridge-work, this being especially noted as a material which has been strained far beyond its elastic limit, and which possesses

a maximum of strength with a minimum of stretch. In this connection it may not be amiss to mention some experiments made by Col. W. H. Paine, M. Am. Soc. C. E., when the matter of the specifications for the steel wire of the cables of the East River Bridge was under consideration. The exact details I cannot give, but they consisted in dropping a weight lengthwise of a suspended wire so as to strike an attachment at the lower end of the wire, and thus subject it to a heavy shock. It was found that with the same weight, the longer wires would resist the shock (even with a greater fall), while the shorter ones would be broken. The greater length in the longer wires gave a longer space in which to arrest the motion of the weight, and the shock was safely borne.

Now, when wire is used in suspension bridges, we have always a large number of wires side by side, and we can, with entire certainty, avail ourselves of the average strength of the material. In addition to this, the great length of the cables permits of a thoroughly elastic reaction, even with a very small amount of stretch remaining in the wire.

In ordinary bridge members, the case is quite different. We are dependent upon one, or at most a very few parts in one member. If these have been strained beyond the elastic limit, incipient rupture may have been developed, and the stresses, owing to deformation, may no longer be uniformly distributed.

D. J. Whittemore, Past President Am. Soc. C. E.—In testing iron the first lesson taught is, that the strength increases and ductility decreases within certain limits of stress, when the initial elastic limit is exceeded; and this being so it is quite reasonable to suppose that when the metal is afterward tested by tensile strains in any other direction, the same condition will be apparent.

The railway company with which I have been connected for many years, has increased its mileage by about one-half by the absorption of other lines having bridges designed for the loads of years ago. In renewing these bridges, after they had been subjected to modern loads, it was found that some of their truss rods had stretched several inches. In rebuilding I felt perfectly safe in using these rods again, but was careful to place them one or two panels ahead of their former position in the truss, or to places where the strains upon them would not exceed 10 000 pounds per square inch, and as yet have noted no failure.

Perhaps it is unwise or not prudent for me to say this to the young engineer, but the peculiarity mentioned gives me great faith in the re-use of iron that has been subjected to strains somewhat beyond the limit of elasticity, but not enough to very materially decrease the ductility.

George E. Thackray, M. Am. Soc. C. E.—I do not clearly understand from Professor Johnson what kind of material he proposes to use in structures. Does he advocate the use of material strained above or beyond the elastic limit?

Prof. Johnson.—No.

Mr. Thackray.—Then I evidently misunderstood his statements.

Prof. Johnson.—I am not recommending anything. I think engineers might relieve their minds of that feeling which I have found exists, that when iron has been once strained beyond its elastic limit it is injured permanently. Not that we are going to strain all our iron beyond the limit and beyond what is due, not at all, but that we relieve ourselves of this anxiety in regard to the continued use of material which has been so strained.

George R. Hardy, M. Am. Soc. C. E.—If an experience with old iron is of any use, I can speak of a case where some bridges had been in use a number of years; even the wood had become weakened so that to get the old iron we had to take down the bridges, but in doing so as the rods were dropped to the ground below, most of them broke off as brittle as glass; I don't think we could take any advantage of that old iron.

Prof. Johnson.—That had probably not been strained beyond its elastic limit.

Mr. Hardy.—I think it had.

William Metcalf, M. Am. Soc. C. E.—There is one statement in the paper under discussion, against which I wish to make a respectful protest; it is, like many such statements, a general conclusion drawn from insufficient data. Coming as it does from so eminent an authority, it is calculated to mislead the younger members of the profession, if it be allowed to pass here without comment. The remark to which I object is, that "if a metal be subjected to a stress of any kind sufficient to produce permanent strain or set beyond its elastic limit, the ultimate strength will be increased sensibly in all directions about the line of action of the deforming stresses." The author calls attention to cold rolling, and wire drawing, as producing an increase of strength in the opposite direction.

In regard to wire drawing I cannot say, because I know of no experiments upon the strength of wire pulled transversely to its axis; we do know that a moderate amount of drawing or of cold rolling of bars does produce great increase of tensile strength, compressive strength, resistance to flexure, torsional strength and hardness; with decrease of density and a great decrease of ductility; we know from long experience that flat strands, cold rolled, are weakened dangerously across the line of rolling, and to avoid this weakening is one of the most serious problems of the cold roller. With all of this real and apparent increase of strength from drawing or cold rolling, we have great decrease of ductility, with great increase of brittleness. It seems as if one set of facts should be set over against the other carefully, and that the engineer should be left to draw his own conclusions.

Professor Thurston mentions the modulus of elasticity; I have a great respect for the modulus of elasticity, because since I worked it out as a

student in Troy, I never understood its application in formulas involving all manner of strains; for instance, a friend of mine had me provide him with spring bars, of steel mild, medium, and high; of each lot some were left as rolled, some were annealed, some hardened and tempered. They were sent to the Government testing machine at Watertown and tested, when it was found that they all had almost identically the same modulus of elasticity; therefore, to make a good spring you have only to get your bar of the right size by means of your formula which is based on the modulus of elasticity, and then the spring will be just the same whether the bar be mild or high, tempered, untempered, or even annealed. When the specifications for springs were issued finally, they required unusually high steel, well tempered. When asked what had become of the modulus, the reply was, "Oh, we found a great reserve of elastic strength in the high tempered steel."

One more point, a practical one, if you are using cold rolled, or cold drawn steel, it would be well to file a nick in an occasional piece and break it transversely; if the fracture shows a distinct dark or black core, reject the steel, it has been crushed in the rolling or drawing. This black is distinct, and should not be confused with the general dark cast or shade that is often noticed on mild and very good steel. The dark or black part produced by over rolling or over drawing, is so distinct from the true grayish blue of steel, that the shop name for it is the "black heart."

Professor Johnson.—You must excuse me for saying a word for my friend the modulus of elasticity. I simply want to say that we cannot compute any kind of distortion in metals without the aid of our friend, this modulus; you cannot compute the distortion of a spring without this modulus. A spring made of any kind of iron or mild steel will distort under a given load, and has exactly the same kind of springiness up to its elastic limit, as one made of spring steel. An iron spring is just as good as any other spring up to a certain point. I am rather inclined to think that the remarks of our esteemed Chairman on that subject were more worthy of an architect friend of mine in St. Louis, who refused to use steel beams in place of iron beams, because his hand-book told him that steel beams deflected one-fourth more than iron; the book also told him that the loads were one-fourth larger; if he had known about the modulus of elasticity he would have known that it was because of the greater loads upon the steel beams that deflected more, and that for equal sizes and loads they deflect equally, because their moduli of elasticity are the same.

Palmer C. Ricketts, M. Am. Soc. C. E.—The effect of the mechanical manipulation of cold metals (especially of those of the iron class), and of rest after such manipulation, on their elasticity and resistance to rupture, has long been known. To quote from Sandberg's translation, made in 1868, of Styffe's classic work on the Strength of Iron and Steel:

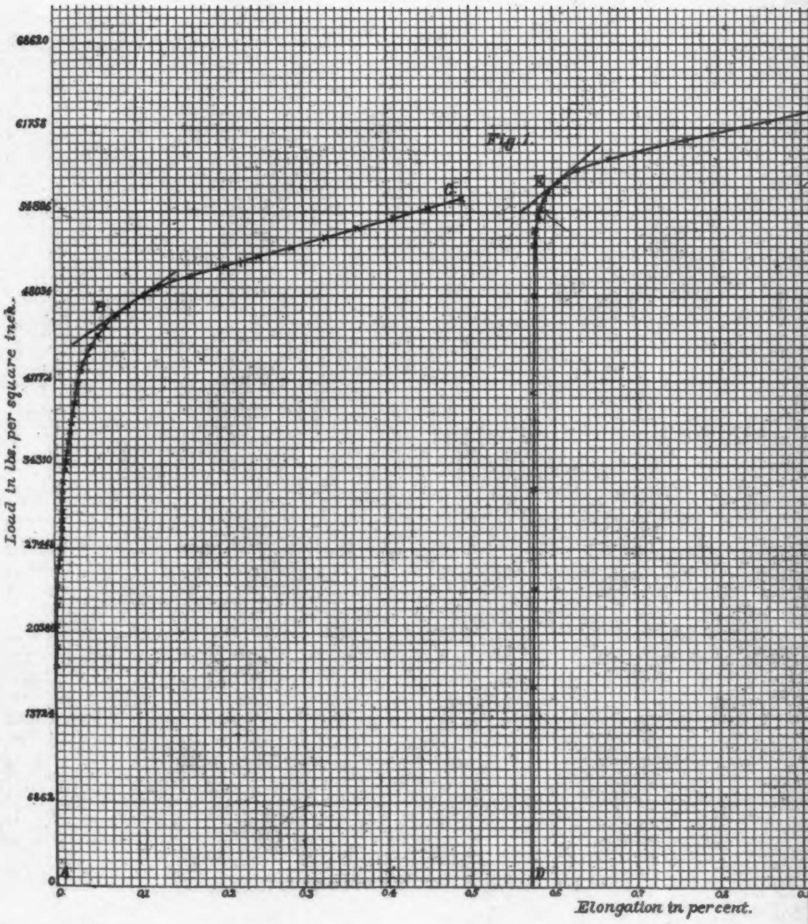
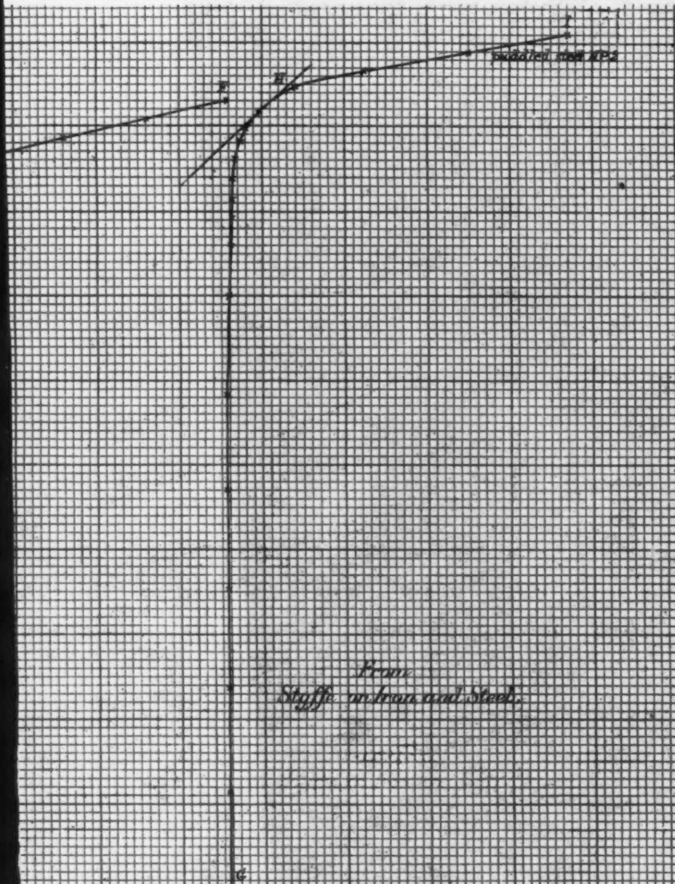


Fig. 1.
Load in lbs. per square inch.
Elongation in per cent.
A
B
C
D
E
68620
61758
54896
48034
41172
34310
27448
20586
13724
6862
0
0.
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

PLATE XVI.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXIV. Nº 465.
RICKETTS ON
STRAINS IN METALS.



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"INCREASE OF LIMIT OF ELASTICITY BY STRETCHING AND OTHER MECHANICAL MEANS.

"It is well known that the limit of elasticity in metals may be raised by cold-hammering, cold-rolling, wire drawing, or by any other manipulation which, acting in the cold, tends to change the relative position of the molecules of the metal. This method of increasing the elasticity is indeed often taken advantage of by workers in metal. We shall afterward show that the absolute strength may also be augmented by similar mechanical treatment, but that the extensibility is at the same time diminished.

"In order to show in what proportion the limit of elasticity is raised by tension, let us refer to the plate (reproduced in Plate XVI of this article), where the curve *A B C* represents the elongation which a sample bar has obtained by loads amounting to 55 925 pounds on the square inch; whilst the curves *D E F* and *G H I* show the elongations produced when the same bar, after having been stretched ten times by a force of 1 029 pounds per square inch, was again tested with a smaller weight, which was gradually increased to 63 816 pounds per square inch; and, finally, for the third time, was submitted to the action of the same force as at the commencement. In these curves all the points determined by observation are marked with a cross. In the curve *A B C* the limit of elasticity is placed, according to the first experiment, at 47 004 pounds; according to the second at 57 279 pounds; and to the third at 63 160 pounds. The limit was thus raised by tension 16 126 pounds.

"The same plate also shows that the upper parts, *B C*, *E F*, and *H I* lie in the continuation of the direction of each other. By experiments with several other sample bars of iron and steel, the author is persuaded that the same thing always occurs when a bar is stretched beyond its limit of elasticity, and then submitted to fresh tension, provided that the new series of experiments closely follow the previous ones, and that the temperature during the whole time has not varied to any great extent. If, on the contrary, the bar be allowed to rest a while before the experiments are renewed, and especially if it be gently heated (for example, to 300 degrees Fahr.) the limit of elasticity is often found to be much higher than might have been expected, in consequence of the tension to which it was previously submitted."

The distinguished author of the paper under consideration, who has done so much to increase our knowledge of the physical properties of metals, also showed independently in 1873, that a similar increase resulted when these metals were subjected to torsional strains. The experiments of Gilmore showing the effect of torsion, and of Parker showing that of cold bending on tensile resistance, are also noticeable.

Although these and similar facts have long shown the possibility of subjecting structural material to stresses beyond the primitive elastic

limit, without imminent danger to the structure (in fact, cases in which the end tension members of old Howe truss bridges have doubtless been often so stressed, have probably come within the experience of most bridge engineers); and although advantage has often been taken of the knowledge of the effect of cold working, to produce material with special qualities suitable for the purpose for which it was intended (as, for instance, wires for the cables of suspension bridges), the decrease in the percentage of elongation and in the reduction of area, and the change beyond this point in the character of the metals of the kind and of the forms and sizes at present generally used, render it extremely doubtful whether these properties, developed by mechanical manipulation of cold metal beyond the initial elastic limit, can properly be taken advantage of in structural design. This is especially true when it is considered, that known metallurgical processes enable material to be made, with initial properties approximating those shown to exist in the ordinary material in use—caused by straining and rest after the initial limit has been passed—probably of more homogeneousness, and quite certainly more economically than it can be by mechanical manipulation when cold.

The comparatively small change in the modulus of elasticity produced by straining and rest beyond the elastic limit, also affects the question.

Whatever character of metallic material may be fixed upon as proper and allowable for structural uses (opinions upon this question differing, of course, to a certain extent, and also as to whether the properties of the material be fixed by hot or cold mechanical manipulation); there can be no question of the propriety of keeping the maximum induced stress in all cases below the known resulting elastic limit, which may properly be called primitive, and very considerably below it, where often suddenly recurring, as long as distortion is considered to be objectionable. That is, no engineer would be supported "in designing structures in which the stresses approach, or may exceed separately or in combination, the normal primitive elastic limit of his material."

In fact, possible inequalities of material and workmanship, will always render a considerable margin between the induced stress and the elastic limit of the parts considered, advisable and necessary, even where this stress is static and can be quite closely deduced.

In this connection Table No. 1, taken from the report of tests made at Watertown Arsenal, on wrought-iron bars of considerable size, during the year ending June 30th, 1882, is interesting.* The change in the character of the fractures from fibrous cross-sections to those which are largely granular, is especially noticeable; and the well-known effect of heating to redness and annealing after stressing beyond the elastic limit, and of heating to a moderate temperature and cooling, also appears.

* Forty-seventh Congress; 2d Session; Senate; Ex. Doc. No. 1.

TABLE No. 1.

TABULATIONS OF TENSILE STRENGTH OF WROUGHT-IRON BARS, SHOWING ORIGINAL STRENGTH AND STRENGTH AFTER THE BARS HAD RESTED; ALSO STRENGTH AFTER ANNEALING.

No. of Test.	Condition of bar when tested.	Size of bar when tested.			Strains on original section.		Strains on reduced section.		Uniform elongation from original length.	Contraction of area from original section.	Appearance of Fracture.	Remarks.
		Width.	Thick.	Sectional area.	Elastic limit.	Ultimate strength.	Elastic limit.	Ultimate strength.				
		In.	In.	Sq. in.	Lbs. pr. sq. inch.	Lbs pr. sq. inch.	Lbs. pr. sq inch.	Lbs. pr. sq inch.	Per ct.	Per ct.		
993	Original	3.05	1.00	3.05	29 500	51 150	......	......	21	31.5	Fine fibrous.	
	Rested four months since original test	....	....	....	......	60 000	......	......	24	....	Fibrous, 90 per cent.; granular, 10 per cent.	
994	Original	3.05	1.00	3.05	28 500	51 110	......	......	21	36.1	Fine fibrous.	
	Rested four and two-third months	....	....	...	53 440	61 960	......	......	25	33.8	Fibrous, 92 per cent.; granular, 8 per cent.	
981	Original	3.05	1.01	3.08	28 000	50 390	......	......	14	35.1	Fibrous.	
	Rested five months	....	....	....	......	60 390	......	......	20	21.8	Granular, 70 per cent.; fibrous, 30 per cent.	
973	Original	5.05	1.28	6.46	27 500	50 500	......	......	13	24.2	Fibrous, 95 per cent.; granular, 5 per cent.	
	Rested eight months	....	....	....	56 500	58 980	......	......	18	17.	Fibrous, 30 per cent.; granular, 70 per cent.	
	Heated cherry red and cooled in open air.	4.75	1.17	5.56	21 670	36 220 41 640	26 080	42 090 48 380	33	....	Fibrous	Broke at end of annealed section.
774	Original	3.03	1.01	3.06	29 500	53 630	......	......	16	36	Fibrous, 92 per cent.; granular, 8 per cent.	
384	Rested ten months	2.84	0.94	2.67	53 920	63 130	61 800	72 360	23	21.9	Granular.	
385	Heated dull red and cooled in open air	2.80	0.92	2.58	22 800	41 240	27 130	48 910	32	34.0	Dull fibrous.	
777	Original	3.03	1.01	3.06	29 000	53 560	......	......	15	37.9	Fibrous.	
386	Rested ten months	2.87	0.95	2.73	53 920	63 070	60 440	70 696	19	19.6	Fibrous, 10 per cent.; granular, 90 per cent.	
387	Heated to 370 degrees and cooled in open air.	2.83	0.92	....	57 520	57 520	67 700	67 700	19	34.6	Fibrous, 60 per cent.; granular, 40 per cent.	
	Rested fifteen days after third test	....	....	....	......	62 420	......	......	....	....	Fibrous, 60 per cent.; granular, 40 per cent.	
971	Original	3.03	1.01	3.06	32 500	53 500	......	......	16	27.5	Fibrous.	
388	Rested nine months	2.84	0.94	2.67	55 880	63 360	64 040	72 620	21	19.9	Fibrous, 30 per cent.; granular, 70 per cent.	
389	Rested nine months	2.84	0.92	2.61	......	66 010	......	77 400	21	19.9	Fine granular.	

The experiments made by Mr. Bissell are very ingenious and instructive. In the line of his Series A, and to show perhaps a little more strikingly the effect on tensile resistance of stressing metal beyond the elastic limit, the writer had three bars of machinery steel and two bars of bronze of unknown composition, all about $\frac{3}{4}$ inch in diameter and about 22 inches long, turned down as shown in the specimen lettered *X* in Plate XVII, that is, leaving 4 inches for gripping at one end. Three spaces, each 2 inches long, separated by distances of 1 inch, were turned down to about $\frac{1}{2}$ inch in diameter, and the remaining 10 inches of the bar were left of the original diameter. These bars were then tested by tension until a decided set was obtained in each. Leaving the 4 inches for gripping at one end as before, the specimens were then turned down for a length of 14 inches to uniform diameters of somewhat less than $\frac{1}{2}$ inch, which left about 4 inches for gripping at the other end. They were then again subjected to tension until decided necking resulted, and in this condition are shown at *A*, *B*, *C*, *D* and *E*, in Plate XVII. The specimens were elongated in this test until the distance between the shoulders, in the steel pieces, was about $15\frac{1}{2}$ inches and in the bronze pieces about $14\frac{3}{4}$ inches.

In all cases the neck formed in the 6 inches near one end, which had not originally been turned down and at distances from the end of the piece given in Table No. 2.

In all of the steel pieces the effect of the strain due to the first test is strikingly shown; those portions which were turned down at first—three spaces, each 2 inches long—remained of the same, or nearly the same, diameter after the final test (see columns II, IV and VI of Table No. 2), whilst the two portions between them, each 1 inch long, and the portion 6 inches long near one end, which were not turned down until after the first test, were reduced decidedly in cross-section (see columns I, III and V of Table No. 2), thus giving the specimens a wavy appearance with three alternating nodes and depressions, apparent at a glance. These show in the photograph, and may be seen in Plate XVII, reproduced from it.

In Table No. 2 the various diameters, measured to thousandths of an inch, before and after the tests, show this clearly. As may be seen from Plate XVII, columns II, IV and VI of this table refer to the parts 2 inches long turned down at first, and columns I, III and V to the parts not turned down until after the pieces had once been subjected to tension.

This wavy appearance, as was to be expected, is not so apparent in the bronze specimens, though it may be seen in the one marked *E*, and it is decidedly shown to exist, though in a lesser degree than in the steel pieces, by reference to Table No. 2.

The necking of the bronze pieces at the points shown was somewhat unexpected, from the fact that the reduction of area in each specimen

PLATE XVII.
TRANS. AM. SOC. C. E.
VOL. XXIV, No. 465.
RICKETTS ON
STRAINS IN METALS.

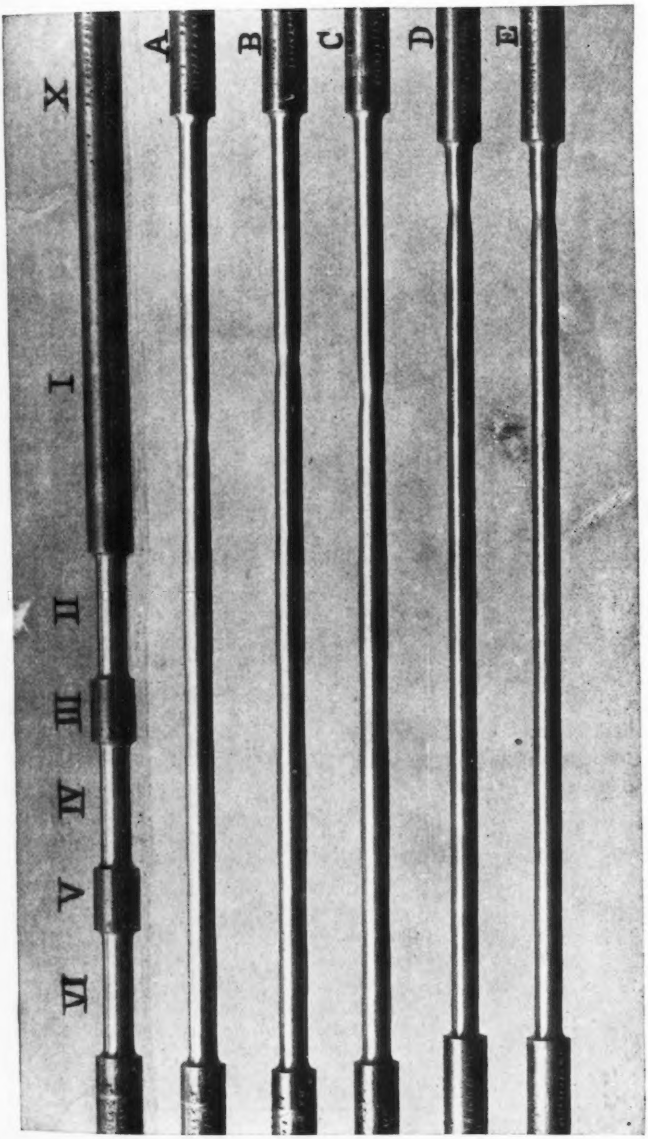

TABLE No. 2.

Mark.	Material.	When diameters were measured.	Diameters in Inches at Points Numbered.							Remarks.
			I.	II.	III.	IV.	V.	VI.	Neck.	
A	Machinery—steel	Before testing...........	0.765	0.510	0.765	0.510	0.765	0.510		
		After first test...........	0.765	0.501	0.765	0.501	0.765	0.501		
		Turned 14 inches long...	0.494	0.494	0.494	0.494	0.494	0.494		
		After second test.........	*0.468	0.493	0.463	0.493	0.468	0.489	0.402	Neck 9¼ inches from end.
B	Machinery—steel	Before testing...........	0.765	0.509	0.765	0.509	0.765	0.511		
		After first test...........	0.765	0.500	0.765	0.499	0.765	0.501		
		Turned 14 inches long...	0.497	0.497	0.496	0.496	0.495	0.495		
		After second test.........	*0.463	0.496	0.465	0.492	0.471	0.488	0.389	Neck 8 inches from end.
C	Machinery—steel	Before testing...........	0.765	0.509	0.765	0.509	0.765	0.509		
		After first test...........	0.765	0.498	0.765	0.498	0.765	0.498		
		Turned 14 inches long...	0.492	0.492	0.490	0.490	0.492	0.492		
		After second test.........	*0.462	0.490	0.461	0.490	0.466	0.486	0.385	Neck 8½ inches from end.
D	Bronze......	Before testing...........	0.748	0.508	0.748	0.509	0.748	0.508		
		After first test...........	0.748	0.475	0.748	0.499	0.748	0.499		
		Turned 14 inches long...	0.458	0.458	0.458	0.458	0.458	0.458		
		After second test.........	*0.450	0.458	0.452	0.458	0.457	0.458	0.364	Neck 5 inches from end.
E	Bronze......	Before testing...........	0.748	0.509	0.748	0.509	0.748	0.509		
		After first test...........	0.748	0.499	0.748	0.494	0.748	0.474		
		Turned 14 inches long...	0.471	0.471	0.471	0.471	0.471	0.471		
		After second test.........	*0.468	0.471	0.451	0.47[illegible]	0.464	0.471	0.379	Neck 5¼ inches from end.

* Measured far from the neck; this portion was, of course, conical near the neck.

during the first test, was not uniform in the turned down portions, but was decidedly greater in one of these portions of each piece than in the others, thus showing weakness at these points. This may be seen by referring to column II, bar *D*, and column VI, bar *E*. Both necks formed, however, in portions not turned down until after the first test. It should be stated that an interval of about five days elapsed between the first and second tests of all the specimens.

R. H. THURSTON (closing the discussion).—Taking up the points made by the speakers in the order of their presentation.—I agree with Professor Johnson in his remark that the facts to which he refers are not to-day new; they were presented by me to the Society as early as 1873-74, if I remember aright, and will be found in the *Transactions* of about that time (1). I think, however, the particular facts illustrated by the experiments here recited in the paper are novel, except so far as given by me elsewhere. A report made by me to the American Iron Works, many years ago, contains an account of the most extensive, and, I think the only very extended investigation of the action of cold-working, ever made. That firm will probably be able to supply copies to members who desire them. An abstract of the work will be found, perhaps amply sufficient for present purposes, in my "Materials of Engineering," Vol. II, in the chapter on "Conditions Modifying Strength," as well as a development of the other points now presented by the first speaker (2). I see his experiments date 1878; mine go back far beyond that time. The fact that strain does not necessarily injure materials of construction was shown by me about the same time, in papers read before this Society, of which that on the permanent registry of the strain by elevation of the elastic limit, is perhaps the most interesting in this connection (3). In one case I suggested the practicability of first testing a bridge-bar to its elastic limit, to insure that it is strong and safe, and then putting it in the bridge—a perfectly feasible thing (4).

Mr. Skinner thinks this impracticable. I think it will be found perfectly practicable with the testing machines now becoming common. The testing of the member within the elastic limit is perfectly safe, and yet gives a reliable gauge of the value of the piece. Once the character of the material is revealed by an investigation which enables the engineer to show the early part of the curve, as in the diagrams of Mr. Ricketts, the rest becomes sufficiently well established—knowing as we do the nature of the composition of the metal—and we can then, if this first part is satisfactory, put the piece in its place with perfect safety and confidence. The extensive use of cold-rolled iron and steel is ample evidence that this is the fact in many directions in the arts. There are, it is true, many cases in which the effort demanded to carry the member up to its elastic limit is too great for ordinary testing-machines; but we have the Watertown machine—once in a while, at any rate—and there are a number of 200 000 and 300 000 pound machines in existence, to say nothing

of the million-pound machine at Athens. I have just started a 300 000-pound machine for Sibley College; we have already a number of others of smaller sizes, and shall have more in the course of the year; so that it may safely be assumed that between the builders and the technical schools we shall be able, in time, to do even this sort of work.

I think Professor Johnson is right in his views relative to this matter.

Professor Eddy's discussion is very interesting; and I think we owe him hearty thanks for thus summarizing the work done to date by the builders of the "theory," which is better called, I think, the true philosophy of the subject. It has always been to me a matter of much surprise that engineering authorities have so closely followed the mathematicians in developing simply a theory of elasticity. While it is true that, so long as the member, in any structure, is doing only its regular and proposed work, its action is completely covered by such theory; yet it is also true that, the instant a critical condition arrives, through accident or the effect of overloading due to carelessness or decay of strength with age and corrosion, the theory of elasticity no longer applies, and that of permanent strain, as well as stress, must be resorted to. I have called attention to this fact in my own work, and, on referring to my Materials, second volume, where the expressions for resistances to transverse and torsional strain are deduced, it will be seen that I show there that the apparent discrepancy sometimes asserted to exist between the theoretical and actual behavior of metal may be fully accounted for by these facts (5). The behavior of a member beyond its elastic limit becomes a matter of serious importance the instant it is overstrained.

Mr. Collingwood's remarks have, in this relation, an importnnt significance. It might also have been remarked that the self-regulating and self-adjusting power of the metal, when under the action of forces producing progressive distortion, is a very interesting and valuable property. Thus a wire or a rod under tension, if first pulled beyond its momentary elastic limit, then allowed to rest, then pulled again, then resting, and so on, will finally be found to have produced, by an automatic action, if I may use that term, a very uniform resisting power, from end to end, irrespective of minute ordinary variations of original elastic and ultimate resistance. I am fully in agreement with Mr. Whittemore as to the re-use of strained metals, and think it will often be found that they are thus made all the more valuable and safe for certain purposes; as where stiffness and rigidity, and the retention of their original dimensions and form is the most essential matter. If he put his old bridge-rods where, in case of overloading, they shall not be those on which most extension must occur, he will be sure to increase the safety of his bridge by their use (6).

The cases mentioned by Mr. Hardy are not uncommon; but I think it will always be found that the defects are not such as bear upon the question here under discussion. Some compositions of both iron and

steel will exhibit that brittleness and progressive crystallization—especially, I think, when containing much phosphorus—which change is due to the repeated stretching of the material by overload and its attempted return to its primitive magnitude; but a wide range of stretch and recoil is, in this case destructive (7). It is only the best qualities, as we find by experience as well as by experimental investigation, that are fitted for cold-treatment. The American Iron Works always get a special quality for cold-rolling; the makers of cold-pressed nuts do the same, and I think the engineer should be as careful in the selection of his materials for bridge-work, in which case he may feel safe with rods previously loaded to the elastic limit.

Mr. Metcalf's criticism has, perhaps, a basis in my own inattention to the collateral facts; but I think the paper, nevertheless, states what it does state with perfect accuracy. The brooming and splitting of bars, to which he refers, is due, not to the stress carried up to and beyond the elastic limit, but even farther, until the metal is actually disrupted. Of course, that case was not contemplated in the paper, or in the work which it described; it does not seem to me necessary that it should have gone outside its title to take up obviously irrelevant cases of that sort. It is perfectly true (as is, I had assumed, too well known to require the introduction of foot-notes on the subject) that decreased ductility always accompanies the elevation of the elastic limit by strain. Where the piece is to be subjected to shocks and blows, this becomes a matter for serious consideration; and the fact should always be recognized and kept in mind. The test which he gives us for injured steel is one which we are all, I am sure, glad to know. I imagine that it comes from the minute separations of particle from particle, due to overstrain. I think that Professor Johnson puts the "Modulus" business in the right light.

Professor Ricketts's contribution of facts to the discussion is most welcome. The older writers, as Morin (long before Sandberg), and also Hodgkinson and others, were well aware of the fact that strain would raise the primitive elastic limit. I think, however, that the first experiment showing precisely how strain, irregularly applied, would produce a peculiar variation of the normal series of elastic limits, as I have called them, was reported by me to this Society in the fall of 1873, as the result of first experiments with my "autographic testing machine." Many other similar investigations followed and were later reported to the Society, in many of which that self-registering system was made useful in revealing, beyond dispute, this singular phenomenon, of which I think I was the discoverer (8). The list which follows, on papers of this character, all of which are in the *Transactions* of the American Society of Civil Engineers, will afford, I think, many interesting facts in this connection.

The action of the bronze is a new discovery, I think; though in my reports to the United States Iron and Steel Board, there will be found

the intimation that such a phenomenon might be now and then observed with certain compositions. This experiment, as reported in the paper, settles that matter. But I am inclined to think that the field is still open for further exploration.

1.—*Transactions* Am. Soc. C. E., 1873: Elevation of the Elastic Limit by Strain. *Transactions*, Vol. II., p. 290. *Transactions*, February 4th, 1874: Strength, etc., of Materials of Machine Construction.

2.—Materials of Engineering, Vol. II.; especially articles 466, 600, 608, 610. *Transactions*, Am. Soc. C. E., March, 1878.

3.—Same; articles 347, 549.

4.—*Transactions*, 1874, as above; Materials, Vol. II., article 299. *Transactions*, Am. Soc. C. E., No. 191, 1880.

5.—See especially articles 261, 262, 263 and 277.

6.—See articles 295, 296, 298, and especially 299. *Transactions*, Am. Soc. C. E., March, 1878.

7.—See article 292 (Crystallization) for some curious facts.

8.—See articles 297, 298, especially figure 137; *Transactions*, Am. Soc. C. E., 1876, 1877; also Metallurgical Review, 1877; Mechanical Treatment of Metals, R. H. T.; and Reports of United States Board appointed to test Iron, Steel and other Metals, 1878.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

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466.

Vol. XXIV.—March, 1891.

DISTRICT STEAM SYSTEMS.

By CHARLES E. EMERY, Ph. D., M. Am. Soc. C. E.

Since presenting at a meeting of the Society, lantern views showing the principal details of the plant of the New York Steam Company, portions only of which have appeared in the *Transactions*, it has been thought desirable to present for publication, at this time, a general statement of the present condition of the plant after a practical test of over eight years; and in connection therewith, to point out lessons to be drawn from this installation, and forecast the probable future of the business.

The writer first examined the subject in the winter of 1879–80, and the Company's organization and plant were so far completed, that work was in progress during part of 1881. Steam was first turned on for use in the spring of 1882, and the supply was extended from section to section as rapidly as the pipes were laid.

In 1886 the plant, though not finished as designed, was in thorough working order in all engineering, mechanical and business details, and the construction of both the up-town and down-town stations had advanced as far as possible under the then existing conditions. The

writer, then manager and engineer of the Company, endeavored to effect some reorganization and retire to a consulting position, but only the preliminary steps were taken and the responsibility remained as before until October, 1887, since which he has had no connection with the work. At that time the basement and three stories of the down-town building, known as "Station B," on Greenwich street, between Cortlandt and Dey streets, had been completed, and forty-eight Babcock & Wilcox boilers, of 250 horse-power each, placed therein, in three tiers; a total of 12 000 horse-power. The fourth story, which was designed to finally receive boilers, had also been partially carried up and roofed over temporarily for the storage of coal, which, it will be recollected, is distributed to the boilers, from the bunkers above, through chutes in front of alternate central supporting columns, the ashes passing to the basement through similar chutes opposite the intermediate columns. A general idea of the building and dimensions of chimney may be obtained from the paper of the writer, Vol. XIV, *Transactions*, page 180. Before 1887, however, another chimney had been added on the north side, shown in Figs. 1, 2, 3 and 4, Plate XVIII. It was made of octagonal section, and covered only one-half the base provided for a second chimney like the first. It started at an elevation of about 130 feet above high water and terminated, like the other, at an elevation of 220 feet above high water, the size being such that another similar chimney could be placed alongside it on the rectangular base. The cap was made of wrought-iron plates with internal iron ribs.

The pipes from the down-town station of the company extend through nearly 5½ miles of streets, and from the up-town station through nearly 2⅓ miles. A small portion of the latter have been put in since 1887, and more boilers have been added in the up-town station to meet the increasing demand. Four new boilers have also been placed in the down-town station, requiring that one-quarter of the fourth floor of the building be arranged to receive them. The system necessarily adopted originally, of temporarily roofing with wood, has, however, been continued.

A general idea of the territory reached by the steam mains could be obtained from a map, but the magnitude of the work can best be judged from a detailed statement of the size of steam mains laid in particular streets in the down-town district, all of which, with the exception of some unprofitable dead ends, are still in operation at a pressure of

from 80 to 90 pounds. The pipes are of wrought-iron, the sizes stated referring to inside diameters for 10-inch, 8-inch and all smaller pipes, and to outside diameters, as is common with boiler tubes, for the 11-inch, 13-inch, 15-inch and 16-inch sizes, the inside diameters of the latter being practically ½-inch less than diameters given.

The first main laid from the Greenwich street station was 11 inches in diameter, and extended northerly through Greenwich to Warren street, with 6-inch branches in Fulton and Vesey streets, extending to Church, and the former connecting to Broadway through a 15-inch line, intended eventually as a supply pipe by another route. The 6-inch branch in Fulton street, has recently been enlarged to accomplish the purpose. There was also an 11-inch line in Barclay street, a 6-inch line in Park place and in Warren street, and an 8-inch line in Murray street, extending to Broadway. Another steam main 15 inches diameter, extended from the station, up Cortlandt street to a cross in Broadway, from which pipes of the same size were run up and down Broadway and in Maiden lane. From Dey street north to Reade street, a double line of pipe 15 inches in diameter was laid, with the intention of eventually connecting the same with the station through Dey street. The Broadway mains north, connected with pipes on the west side in the streets already mentioned, and there was also an 8-inch pipe run on Reade street from Broadway to West Broadway, a branch from which extended along the latter street a short distance. On the east side, a 13-inch pipe in Mail street was connected with an 11-inch in Park row, which extended a short distance down Spruce and Beekman streets. The latter pipe connected with a 6-inch pipe through Theater Alley, which, through Ann street, connected again with Broadway, opposite Vesey street. The 15-inch pipe on Fulton street extended easterly across Broadway to Nassau street, and was continued by an 11-inch pipe to William street. The Maiden lane pipe was 15 inches diameter to William street, and was continued easterly by 8 and 6-inch pipes nearly to Pearl street. South of Cortlandt street a 15-inch pipe ran down Broadway and Whitehall street to the Produce Exchange, with a branch through Beaver to New streets and from thence to Exchange place. There was also a 15-inch line in Wall street, from Broadway to William, extended by a 13-inch pipe to Pearl, and by a 6-inch to Water street. From Wall street an 11-inch branch pipe was extended down Broad street nearly to Exchange place. A 13-inch pipe connected the Wall

FIG. 3.

Section on line B.B.

FIG. 4.

Section on line A.A.

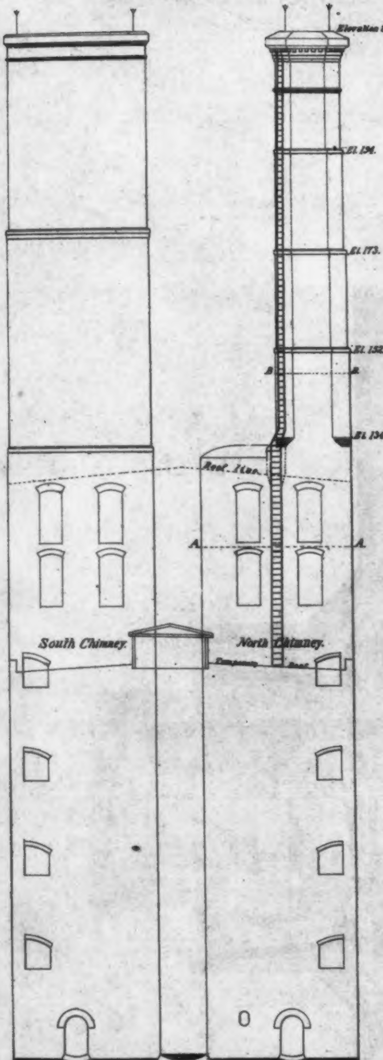


FIG. 1.

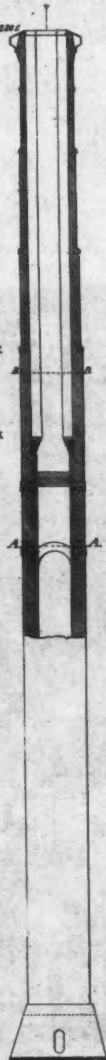


FIG. 2.

FIG. 6.

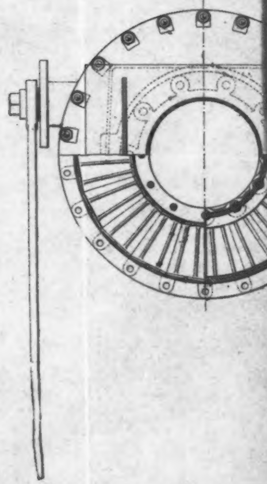


FIG. 5

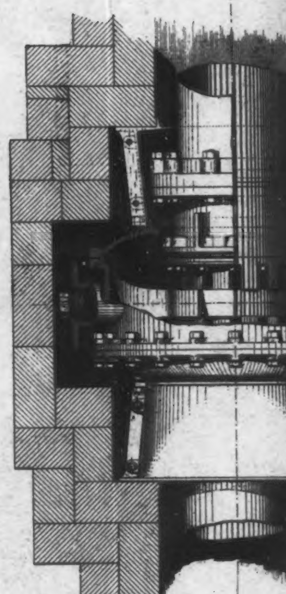


FIG. 6.

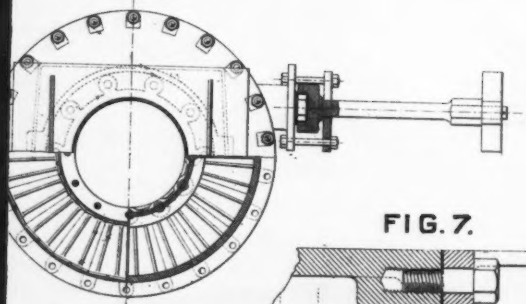


FIG. 7.

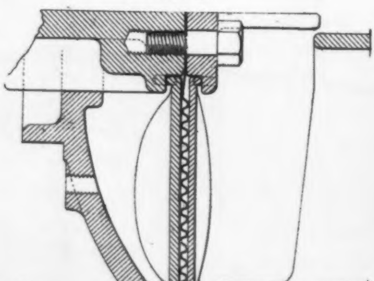
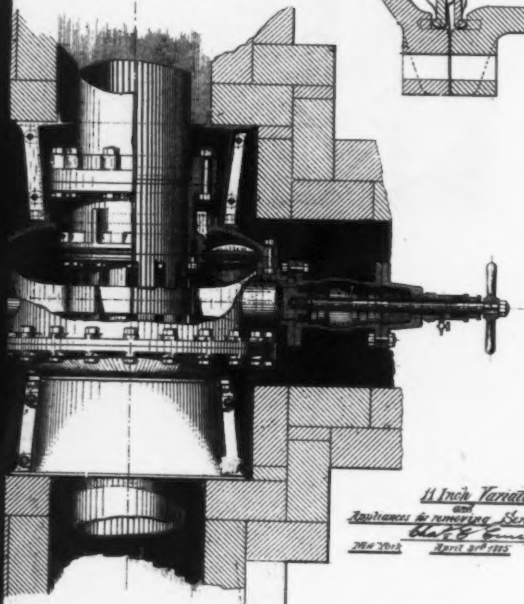


FIG. 5.



11 Inch Variator
and
Appliances for removing Service Plugs.

New York April 3rd 1885

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PLATE XVIII.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXIV. Nº 466.
EMERY ON
DISTRICT STEAM SYSTEMS.

FIG. 8.

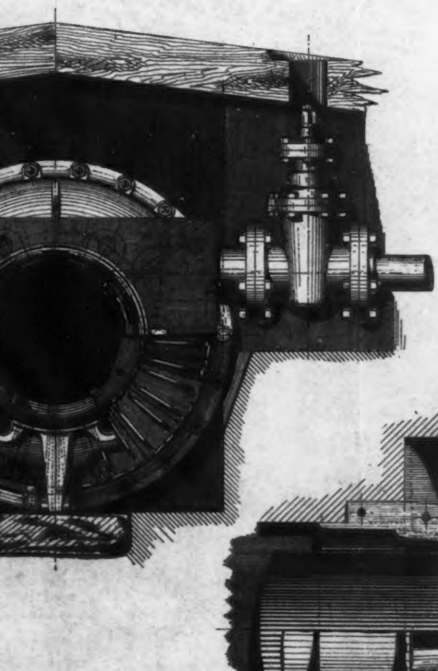
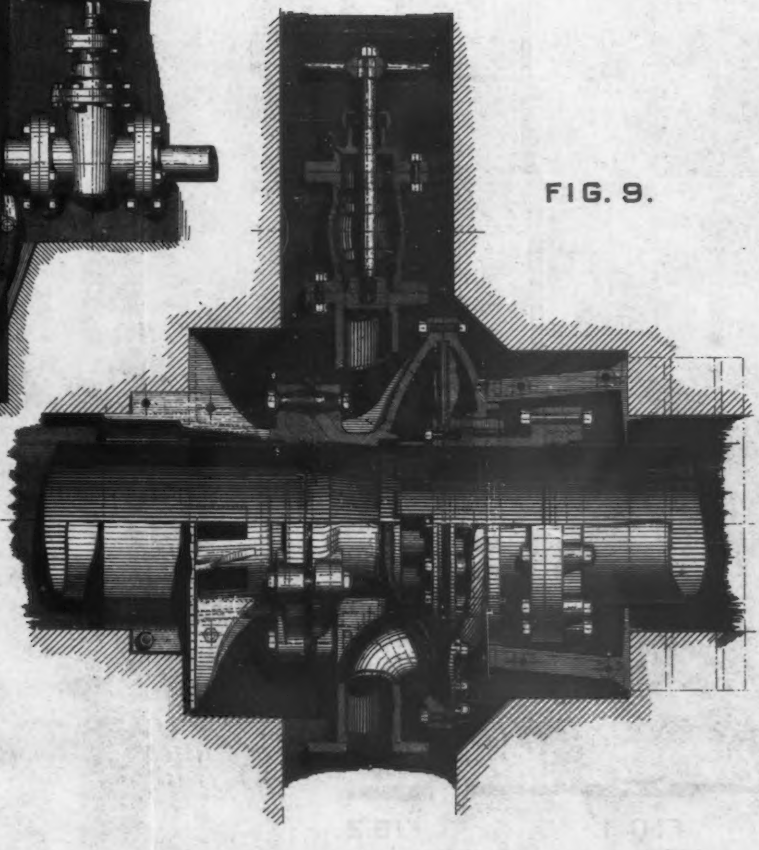


FIG. 9.



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and Maiden lane pipes, through William street, from which last pipe a 6-inch connection ran through Liberty street, from William street to Broadway. On the west side, a 16-inch main runs south on Greenwich street, from the station to Liberty street, where it connects with Broadway through an 8-inch pipe; and the Greenwich street line is continued with 15-inch pipe to Rector, and up the latter street to Broadway. There are also a number of branches of comparatively small pipe which act as mains, and some connections through buildings, and some large buildings have service pipes, all of which are not now in use, of sufficient size to be called mains; there being one to the Produce Exchange 11 inches diameter, one to the Mills Building 8 inches in diameter, another to the Mutual Life Building of the same size, one of 6 inches to the Telephone Building, one of the same size to the Western Union Telegraph Building, another to the old *World* Building, one of 8 inches to the *Tribune* Building, one of 10 inches from Mail street to the New York Court House and Post Office Building, and another of 6 inches from Broadway to the same building. The New York City Hall is supplied through a pipe running under the greensward of the Park. In connection with these pipes, return mains were laid the whole distance. They were 8 and 6 inches in diameter near the boiler house, and reduced to 4 and even 2½ inches in diameter near the ends of the lines.

The up-town station was built in 58th street, near Madison avenue. The building is ornamentally designed with terra cotta trimmings, so as to be architecturally in keeping with the dwellings in the same block; the writer being assisted in the architectural treatment by Mr. W. C. Haslett, architect. The building is on a lot which had been filled in over a former muddy stream, but as it was leased ground, a light building of two stories and basement only was designed, with boilers on main floor and coal storage on the upper floor. The walls between the boilers were supported on arches in the basement, and were carried up to support the coal bins; and there being about 8 feet of old compact filling left below the foundation, no piles were used under the main part of the structure. The chimney, however, was set on a pile foundation, an opening for the same being cut through to the mud. Great difficulty was encountered in driving the piles, on account of broken stone which had been used for filling, in connection with earth, when the streets were graded. The building has stood well, only cracking at one

corner next to an adjoining vacant lot, which was probably filled at a later date. Considerable study was required to utilize the space available. The west end is an office building, with an arch at the side for the entrance of the coal carts. It was at first intended to back the carts in, but to conciliate the neighborhood the plan was changed, one boiler omitted, the steam pipes crooked more than was expected, and the carts now drive in beyond the center of the building, when two trap doors are raised behind, and the coal is dumped through the floor into a loading bin, and from this into a car below, which can be run on an elevator at the side within the lines of the office building. From the elevator it is run on a transfer car on the upper floor, and transferred to rails running over the bins at either side. Similar longitudinal and transfer rail lines are arranged in the basement, so the ashes may be drawn into cars from pans under the boilers, carried up on the elevator and dumped in a bin over the driveway, where they can be rapidly loaded in the carts. The building is designed to contain twelve boilers of 200 to 250 horse-power each, of which six have been put in place. The flues from the boilers are carried around against the walls in the basement. Two 10-inch pipes are laid from this station to Madison avenue. The distribution is on Madison avenue from 54th to 68th streets, with a number of branches, mostly on the west side toward Fifth avenue. There is also a main on Fifth avenue from 58th to 53d street, with some connections in cross streets between Madison and Fifth avenues. This plant was designed like the downtown one to carry 80 pounds of steam and to run summer and winter, but the pressure has in general been kept lower, and steam supplied only during the winter. Recently, Mr. F. H. Prentice, the present Manager and Engineer, has been carrying high-pressure on some of the boilers and supplying electric lighting engines, then using the exhaust at 30 to 40 pounds pressure to partially supply the steam mains. The writer started at one time to convey exhaust steam from an electric lighting plant through street mains for heating, and such a plan was actually carried out soon after in another city, though not at the high pressure Mr. Prentice is now using.

At this date the steam mains are, with the exception of some leaky joints to be referred to hereafter, in apparently as good condition as when laid. A steam pressure of upward of 80 pounds is maintained upon them continuously, night and day. The return main system has proved a failure,

on account of external corrosion, though the pipes were in every way similar to the steam pipes as respects material and fittings, were laid in the same trench, and protected and connected in the same way. Both the steam and return mains were covered with asphalt varnish applied hot with a brush as the pipes were laid; the pipes, however, were not heated. The varnish on the steam pipes still remains; that on the return pipes has been forced off in large patches by ordinary rust. The corrosive action, when once started, was apparently locally cumulative; crater-shaped cavities being formed, which, in due time, penetrated the pipe, allowing the water to escape. This action required several years for its full development. When the writer was connected with the company, the only trouble had been with the smaller return connections, and the action was attributed to the fact that they were alternately cold and hot, under which conditions iron readily rusts in all locations, but particularly when in contact with a porous material which prevents the moisture from evaporating freely. There had been a single case of a small hole in a larger return pipe and a similar one in a steam pipe, which were attributed to cinder rolled in. Later, however, the general action took place and was immediately followed by similar phenomena in the return pipes uptown, which were not laid until several years after. Without going into details, the conclusion reached is, that the carbonic acid in the atmosphere and soil, the principal active element in inducing corrosion, has a particular active effect at or about a temperature of 210 degrees to 220 degrees, corresponding to that in the return mains; that at lower temperatures the action is less violent, and at higher temperatures, like those of the steam mains, the moisture is at once repelled, and any water touching them at once assumes the spheroidal state, so that absolutely no corrosion takes place. The fact that iron corrodes with great rapidity at or about the temperature of boiling water, is believed to be unknown to the majority of engineers. The writer had previously heard of the corrosion of return pipes, the same as he had of boilers, but never in any connection which could not apparently be explained by leaky joints, and alternate heating and cooling of the surfaces. It is doubtless true that in individual cases it was known that pipes in a heating system had corroded rapidly, and it can now be recollected that it was the return pipes which gave the most trouble; but it does not appear to have caused suspicion that the corrosion was not due to differences in location and treatment, or to leaks when alternately heated

and cooled as above mentioned, and so no warning has been given in respect thereto. Mr. James B. Francis, Past President Am. Soc. C. E. states that it was reported to him forty years ago that the return pipes in a certain mill were corroding very rapidly, and that the accompanying steam pipes seemed to be in much better condition, but that the matter went out of mind, and it did not occur to him again until he heard of the difficulties here in New York. One engineer, after hearing the above statement, was kind enough to inform the writer that if he had been asked he could have told about it, as he had observed the phenomena himself in the Eastern mills. Unfortunately this very person was one called in consultation by a proposed investor, while the work was in progress, and his report made no reference to anything of the kind. This fact is mentioned, more to show that even if certain persons were informed in regard to the corrosion of return pipes, it was not mentally separated from other failures by corrosion, sufficiently to cause it to be recollected and specifically mentioned; and the fact that when steam pipes and return pipes were arranged nearly together, under exactly the same conditions as respects exposure, moisture, etc., one set (viz., the return pipes), would corrode rapidly, and the other (viz., the steam pipes), would not—if indeed ever noticed more than casually, certainly was never sufficiently understood to be spoken of in conversation among experts on the subject, or to find its way into standard works. It is true that one pipe fitter would find that his return pipes had corroded, when as he thought, carried too near the cellar floor, and another when, as he thought, the moisture dripped on the same from the walls, but the fact that such pipes corroded more rapidly at or about the particular temperature of return pipes, independent of position, does not seem to have been previously even thought of.

The return pipes of the New York Steam Company finally caused so much difficulty from leakage, that the present management decided to dispense with them, and this has been done on the east side of Broadway and in many streets on the west side, by arranging that the water of condensation from the heating coils of the buildings be discharged to the sewers. This is the method originally adopted by the original Holly company, which, it is well known, has put up a large number of plants for heating buildings in small cities throughout the country. Its general plan in heating a dwelling, was to run the pipes to and from the radiators as usual, and discharge the water of condensation

from the trap through an indirect stack of coils used for heating the main hall of the dwelling, or perhaps the front of a store. In this way the temperature of the water discharged was brought down to 100 degrees in many cases, and the loss of heat and of water formed a small percentage of the total cost. This was known to the writer when originally designing the plant of the New York Steam Company, for which the conditions were entirely different. The Holly people had been working with pressures of 20 to 40 pounds. In New York it was proposed to carry 80 pounds pressure (80 to 90 pounds have been kept up continuously). The steam was to be used for operating engines, and it was absolutely necessary that the mains be drained at every dip. The water taken from these points would necessarily have the full temperature of the steam, and on allowing its escape into the atmosphere one-sixth to one-seventh of it would burst into steam at that pressure, so its direct discharge into the sewers was impracticable. Moreover, the steam was to be conducted to many buildings in which the pressure on the radiators was carried at 40 to 50 pounds. Many lessees had only one floor and the right of passage along the halls and stairs. Many basements were occupied as wine cellars, and no privileges could be obtained for those on the upper floors, except, perhaps, that of running pipes under the care of a watchman. Moreover, the new enterprise had popular prejudices to overcome and municipal regulations to consider, so a return system was provided, the same as is always used in large buildings. The difficulties about getting rid of the steam from the hot water can now be better handled than it could originally, as the company has access to many consumers. In some instances, the discharge from the street traps is brought to coils in the ventilating shafts of adjoining buildings, and the water discharged at a lower temperature. Parties who have control of the basements have in some cases had water coils placed on the returns for heating some part of the building, as in the Holly system. In other cases, arrangements have been made to heat radiators in one part of the floor with steam, and those in other parts with hot water discharged from the trap, though in such cases the distribution of heat is not always as desired. It is, however, difficult to carry out this system perfectly, as originally feared; and considerable steam is finding its way to the sewers, and at places escapes from the sewer manholes in large volumes. The company has adopted the policy of letting each consumer take care of his own water of condensation, so as to avoid discussions in relation thereto with the Department of Public Works.

There have also been serious difficulties with leaky joints, on the steam mains of the New York Steam Company. As is well known to the New York members, the work was prosecuted under the most aggravating conditions of disorganization, which it seems necessary to refer to with sufficient detail to form a sort of engineering precedent, in relation to one of the most difficult problems an engineer is obliged to encounter. With the best of feeling, and with due respect to all concerned, it seems proper to say that the President and promoter of the Company, though a most charming person socially and intellectually, was, when he made his advent in the East, an unusually bright specimen of the Western "hustler" who believed in "looking after things," as it was called; and no amount of persuasion or argument could at first impress him with the necessity in executing a difficult and important work of this character, of organizing and building up a corps of well informed, skillful and reliable employees, who could be trusted to do good work even when out of sight, and left without harassment, with hearts and minds free to do it. On the contrary, every one from the laborers up, was urged to hasten his own work, and called upon around the street corners, at the office, or at the hotel, to report progress and report the shortcomings of others. One gang of men in one street was pitted against those in another. The enormous difficulties in doing such work under such conditions, were aggravated by the fact that a very large amount of money, subscribed through the magnetic influence of the operator, was spent in real estate to give the Company business standing, and the constructive work was done almost exclusively with borrowed money. When the times were good and the banks loaned liberally, the work was pushed, and sometimes more rapidly than good men could be found and educated to do it; and as money tightened there might be a sudden order to reduce the wages of everybody ten per cent., independent of the condition of the labor market, or to put fifty per cent. more sand with the cement, independent of the strength of the mortar. It became necessary repeatedly to suddenly reduce the force, and it was frequently very difficult to save even the principal employees with their valuable experience and special education; and when this was done the harassment due to criticism of their efforts to keep busy without a proper working force, rapidly demoralized them, and the work started up again at the next boom with less vitality than before. The original company which had encased steam pipes in wooden logs, freely gave their advice as to the ex-

travagance of using brickwork; and it was criticised at all times, at all places, and before all men, with lamentations as to the obstinacy and extravagance of the engineer. The curtain may fall on particular details, some of which would seem to be romances. The experience of some of the older members of the Society was appealed to, as to the proper course of action in such cases, but little assistance was gained; most of the suggestions taking a ridiculous form, such as an accidental turning on of a hose and things of that kind. One prominent member of this Society, supposed to have the interests of the promoter at heart, was appealed to, but perhaps, as it proved, in rather too indirect a way, as he felt it to be his duty to report to the promoter that he feared the engineer was not as "loyal" as he should be. This, though discovered long after, partly accounts for the intensity of some of the difficulties. The relatives and business partners of the promoter were consulted, and urged to do something to get the business organized on business principles, put somebody in charge in whom there was confidence and go ahead. Our respected President of the Society, Mr. Shinn (who is not the person above referred to), was called in under the circumstances; and though able as Vice-President to do valuable service in getting the finances and book-keeping on a business basis, and in particular cases in a quiet way in doing much more, he was finally obliged to declare in regard to disorganizing matters, that the President of the Company must alone he held responsible for his acts. The writer, though eventually receiving many signs of confidence and finally promoted to the management, was engaged in a continuous contest, and found that the only way in which progress could be made was first to receive compensation suited to the character of the work; second, to work hard all day and sometimes late in the night, occupying a large portion of the time in untying the knots caused by disorganization the day before, and as much of the time as possible in supervising the design, construction, operation, and business incident to the work; when, declining invitations to discuss matters still later, he would go home and forget everything, whereby he was able to repeat the operation continuously. Under such circumstances this great work was conducted. It is not to be wondered at that some bad work was done; some due to slight imperfections in material which escaped even conscientious inspection; some due to carelessness, as for instance, screwing a drain-pipe only one thread in the bottom of a casting 1 inch thick; some due to the nervousness of the workmen in screwing up the pipes when the

quiet of the neighborhood was broken by the advent of the bundle of nerves, whereby a casting fully twice as heavy as used in ordinary work for the same pressure would be cracked sufficiently to finally give out and require the digging up of the street. Again, laziness would occasionally prevail, and a man attempt to loosen a plug by hammering it with a sledge and cracking the nozzle, instead of walking across the street and obtaining the heavy wrenches, ropes, and tackles which had been provided to perform the operation without risk. All these things, however, account for but a small portion of the difficulties experienced. The principal leakage was caused by imperfections of foundations, due to the failure to construct some of them in the way originally designed, and which was carried out until the disorganization reach its height. It will be recollected that expansion was provided for by diaphragm joints peculiar in construction, called variators, which will be referred to hereafter. They required that the pipe be divided into sections not exceeding 50 feet in length, but as the crosses at street corners must be at the terminations of the sections, the latter were generally a little over 40 feet long. In some cases there were double variators with two diaphragms at the end of the first section, then a small cross called a service box, then a double variator again. At other times there was but one double variator in a block and single variators with one diaphragm were used at the ends of the other sections. The service boxes and single variators were provided with ball joints which could be screwed up in place, thereby eliminating all strains and permitting small changes of direction. The diaphragms of the variators also provided slight flexibility. The plan was adopted of putting in brick foundations extending down to undisturbed earth, and capped with stones set to grade by the engineer, at the end of each section, and this part of the work was well done and never settled. Each section, however, was composed of three lengths of pipe, which, for the large sizes, were flanged together, and the two pairs of flanges thus intervening were, to provide for slight defects in securing the flanges, want of straightness of the pipe, etc., supported on brickwork built after the pipes were put in place on temporary blocking. Each pier was built up within about 3 inches of a flange, a cast-iron support with a flat bottom put against the flange, then the capstone of the pier was put in place and held up against the saddle temporarily with wooden wedges, when the joints on either side of the wedges were grouted, the temporary blocking removed, and the pipes remained

supported without strain exactly as they had been put together. A first it was required that the wedges be removed and the space occupied by them also cemented. This so delayed the work that permission was afterward given to leave them in place, building their ends in the side walls and depending for support upon the mortar at the sides, which was amply sufficient, as the pipes with flanges and mineral wool covering would rarely bring more than 1 000 pounds pressure on an 8-inch pier, so if the masons had carelessly only pointed up the crack at each end so as to give ½-inch of mortar for 16 inches of length, the strain would not reach that ordinarily imposed on brickwork. So important was this work considered, that particular masons were previously trained in the work by the engineer, and if another gang opened another street, this operation was repeated during all the time the work was in progress. Notwithstanding this care, some two years after the large pipes in Broadway were laid, leaks developed, and it was found that for a long stretch in this street, and at points in other streets, as appeared afterward, the cement had been left out alongside the wooden wedges, and the only support for the intermediate joints of pipe, was that obtained from shriveled and charred wooden wedges between the substantial brick piers and their capstones. Gradually but surely the pipes had settled breaking the joints not only in the flanges over the supports but frequently at the other ends of the pipes. The very slight leaks at the beginning, were gradually eroded by mechanical action, and although the slits thus formed would not ordinarily be ⅛-inch wide and half the thickness of a sheet of paper, so small in fact that they could not have been preserved for any useful purpose, yet the steam had become so free from deposit that the leaks did not close, and through the multitude of minute openings the whole soil became saturated with steam. Occasionally one of the openings attained a much larger area. Eventually every defective joint had to be dug up and the leaks stopped in various ways. The larger pipes, of which the outside diameters are given at the beginning of this paper, were secured in the flanges, by rolling with large expanders in a bell-shaped groove, the ends of the pipe abutting against a shoulder to take the longitudinal thrust. These joints had proved excellent on preliminary tests, and each pipe was tested after the expansions were made; but to provide for any possible failure, an annular groove was left in a hub-like extension so that calking material could be put in the same, around the pipe, at any time. These

spaces were originally filled with lightly driven rust joints, simply to give stiffness to the flanges. As leaks occurred, the rust joint material was cut out and lead wire driven in, copper proving so rigid that it would increase the leaks. It will naturally be supposed that screw joints would have been better, but in one locality the same action took place on 8-inch pipe with screw joints, and the leaks were worse than with the rolled joints; for the reason that the erosion cut off the points of the threads, and from the usual confidence in screw joints no grooves had been provided for calking purposes. Every one of these joints, therefore, was necessarily made tight with followers bolted on in halves and held together on opposite sides of the flanges by through bolts. The same process proved necessary also on the rolled pipe when the leaks broke out a second time, as with the slightest leak the lead would be rapidly eroded. Lead proves to be excellent even for steam joints, if means be provided to overcome its lack of elasticity. The pressure produced by comparatively long bolts, well screwed up, seems to be sufficient to accomplish this purpose. The work on Broadway, on account of the position of the railroad tracks which had been laid directly over the pipes, cost on the average more than $120 for each joint, so about $50 000 was spent on this street alone, frequently stated to be five or six times that amount. No calking that could he applied made the pipe joints as good as they were originally, so, as was expected, from time to time leaks have broken out, but not to any general extent; the steam now appearing through the sewer manholes being largely due to dispensing with return pipes, as explained elsewhere.

In attempting afterward to ferret out the reason why the cement grouting was omitted under the capstones of the intermediate foundations, the masons claimed that it was due to a direct order from parties other than the engineer; but whether it came directly from the one who had been persuaded that wood was as good as brick, or whether another who had been saved from dismissal and desired to please his benefactor, simply misunderstood the earnest conversation of the latter, and thought to please him by taking him at his word, will probably never be definitely settled.

After the difficulty developed, the cast-iron saddles were grooved on the bottom, and iron wedges applied in the grooves against the stones to hold the saddles up to the flanges on the pipe. It may be asked why this was not done in the first place, but it is submitted that the arrange-

ment first used was a proper one. The pipes were originally blocked up so that the flanges were parallel, and when bolted together lay on blocks without strain. The problem was simply to hold them there. The method adopted, where carried out, did this perfectly. On the other hand the iron wedges could be operated by careless workmen so as to lift the pipes too much, and to do as much injury by straining the joints upward as if they settled in a like degree.

It is gratifying to state that the expansion joint, used on the steam mains, has proved a success from the beginning. It has been called a variator (see Figs. 5 to 9, inclusive, Plate XIX). It will be remembered that the principal feature is an annular copper diaphragm with circular corrugations, clamped at the center to an extension of one of the pipes, and on the outside to the body of the variator. A section of a diaphragm is shown clearly in the enlarged view, Fig. 7. The diaphragm is supported on ribbed plates of radial outline, the ends of which rest on ledges as shown. The outer plates are heavily ribbed and receive the steam pressure, being protected by a curved bonnet, which also guides the central hub to which the center of the diaphragm is attached. An inner set of lighter plates are also provided to resist the pressure of the atmosphere in cooling off the pipes. In the "double variator," shown in Fig. 5, two diaphragms are used with connections for main pipes facing in opposite directions. In the "single variator," shown in Fig. 9, but one diaphragm is used, with one pipe connection like that described, and another formed by drawing the body of the variator itself in bell form down to the size of pipe. The reduced end of the body is in all cases provided with a ball joint, as shown, so that the pipes may be put together without strain and with slight differences in alignment.

These drawings also show the method adopted of connecting the services. As shown, each outlet is provided with a flange, and is ordinarily closed by a plug in the opening. It is tapped, under pressure, by first loosening the plug with a very large wrench, then bolting the valve permanently to the flange, and temporarily applying to the outer flange of the valve a tool with a central mandrel, having on its inner end a left-hand thread which engages with a hole similarly tapped in the plug. By revolving the mandrel to the left the plug is removed, the pressure admitted to the valve, and, by pulling the mandrel back and shutting the valve, a connection is made in a very few minutes, through which steam for 70 to 100 horse-power can be taken.

The general arrangement of fittings at junctions is shown in Figs. 10 to 21, inclusive. Fig. 18 shows the construction at the large elbows where the steam leaves the station, and the others show the general appearance of the pipes in the ground with conduits uncovered. Fig. 21 illustrates the flexibility of the system. The pipes were first laid in the open trench supported on brick piers, referred to elsewhere, when brick walls were built up around them so as to leave a space of about 4 inches at all points, which was filled with mineral wool in bulk. The conduit thus formed, was covered transversely with a roof of heavy plank made by sawing up the timbers of old buildings, the brick courses being arranged so that the covering was slightly inclined. An outer covering of tarred paper was extended over the planking and down the sides of the brickwork, nearly to the bottom, and smeared with hot coal tar. It was considered that dry wood, separated from the steam pipes by mineral wool, would last for many years and until the pipes would need examination. Flagstones were used in some cases, and can be applied at any time in making examinations. It is not thought that the system of constructing the conduits can be improved. The mineral wool covering is all that can be desired as a non-conductor, and appears to be efficient for this purpose, but a less quantity can probably be used without a serious loss of heat. A flagstone covering would be more permanent, though the wood, even during recent examinations, proves to be in excellent condition, and is charred slightly only where subjected directly to a considerable steam leak.

An important question arises as to how return pipes should be constructed in locations where it is desirable to use them, in view of the corrosion which has taken place in such pipes in New York. It has been the opinion of the writer that the true course of action is simply to use rolled brass pipe instead of iron, and to continue to make the fittings of heavy cast-iron as heretofore. The additional cost of brass pipe is well warranted. It will be found on calculation that if the feed water of the boilers be pumped into the boiler at a temperature of 200 to 212 degrees, instead of that of the ordinary city supply, there will be a saving of about 10 per cent. in fuel. Further, it will be found that the amount of coal consumed in a district system per year, will equal or exceed in value the cost of the pipes necessary to distribute the steam which such fuel will generate. It follows, then, that if 10 per cent. of the fuel is saved, that this saving will pay 10 per cent. on

FIG. 11.

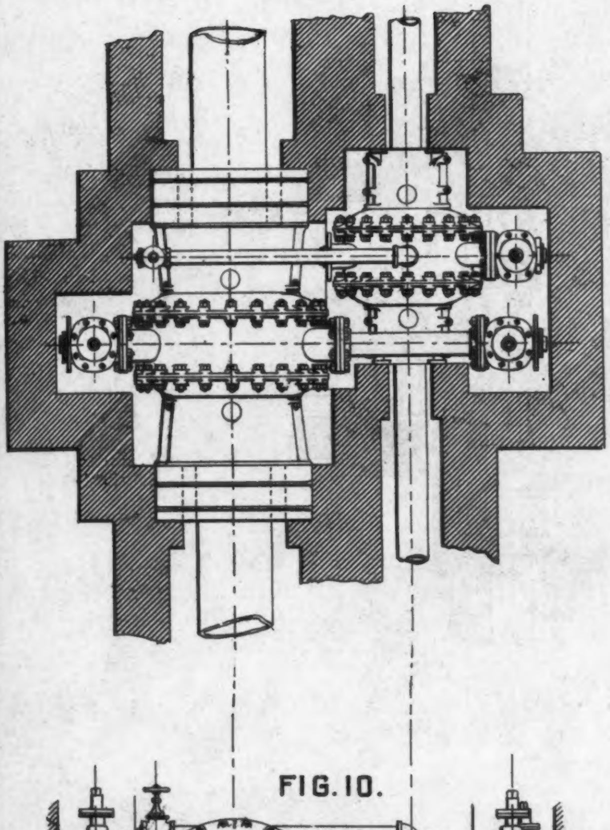
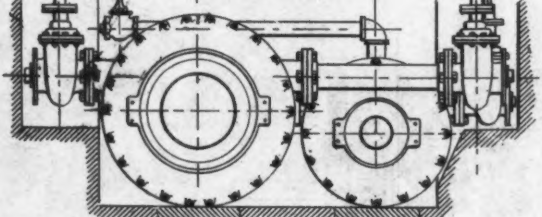
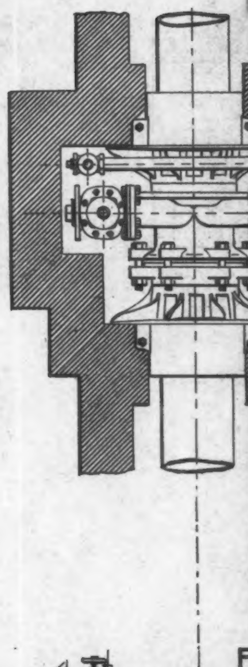


FIG. 10.



FIG



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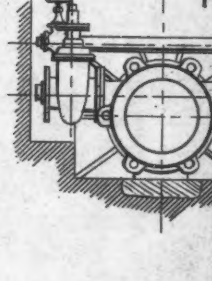

PLATE XIX.
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FIG. 13.

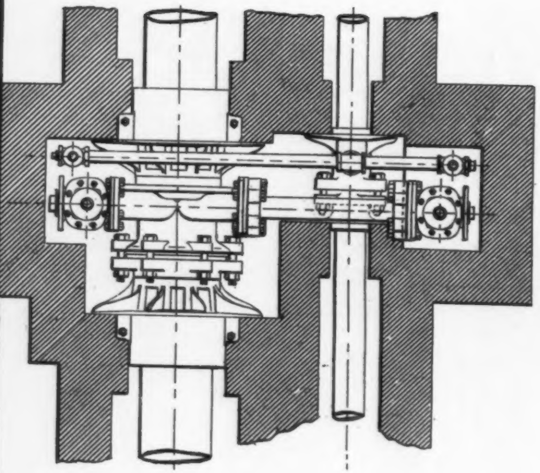


FIG. 12.

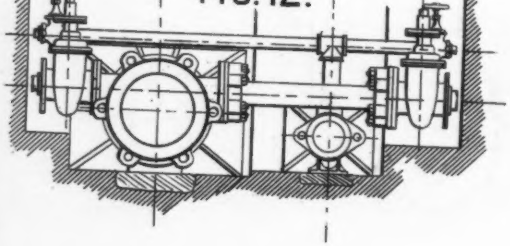


FIG. 15.

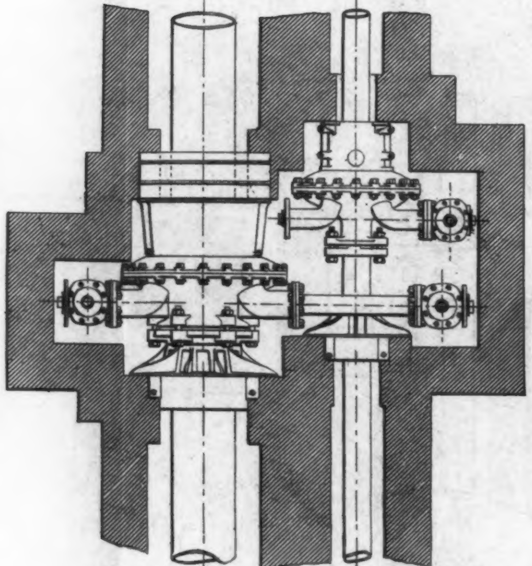


FIG. 14.

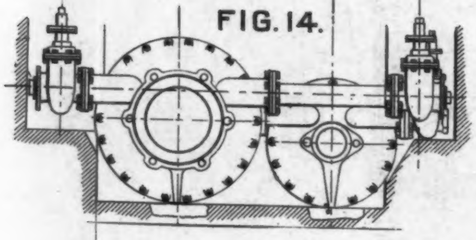


FIG. 17.

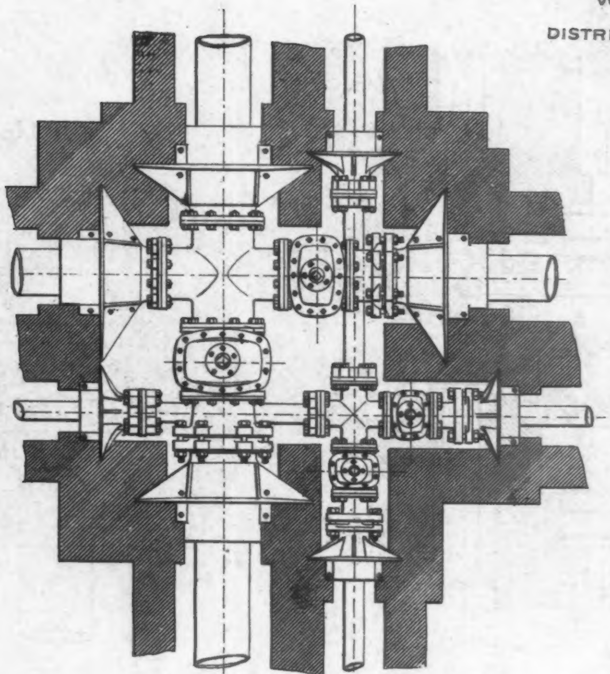
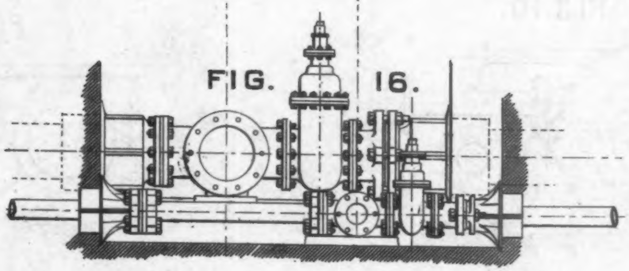


FIG. 16.



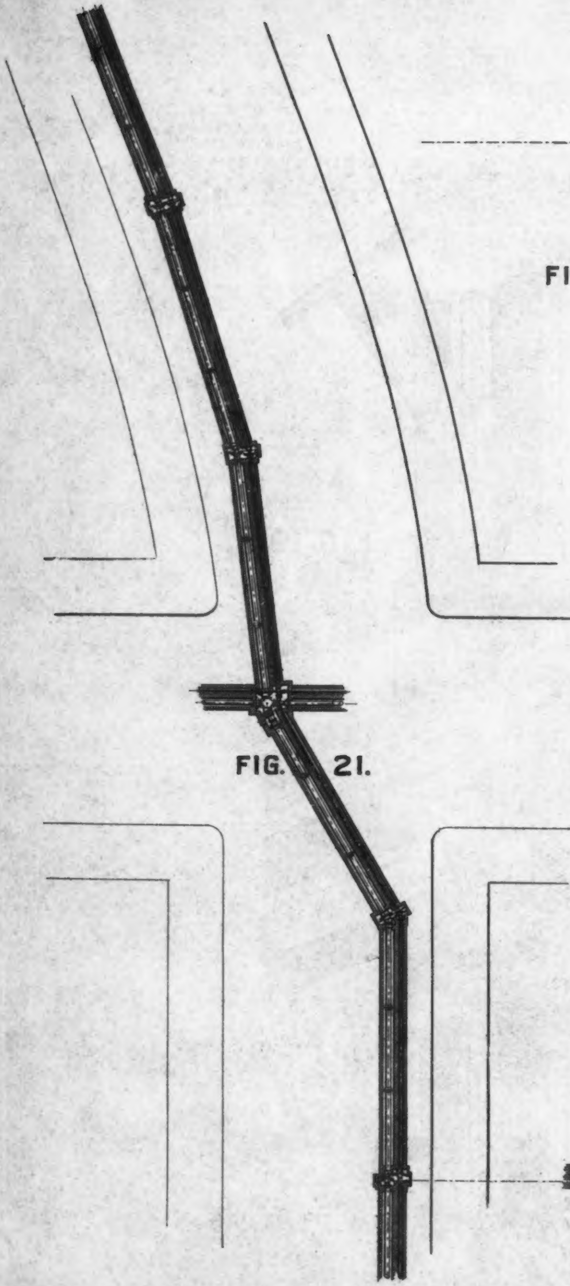


FIG. 21.

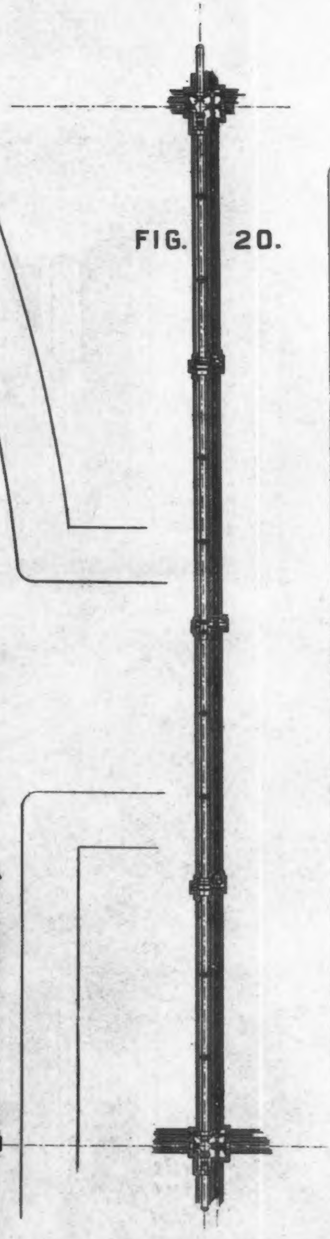


FIG. 20.

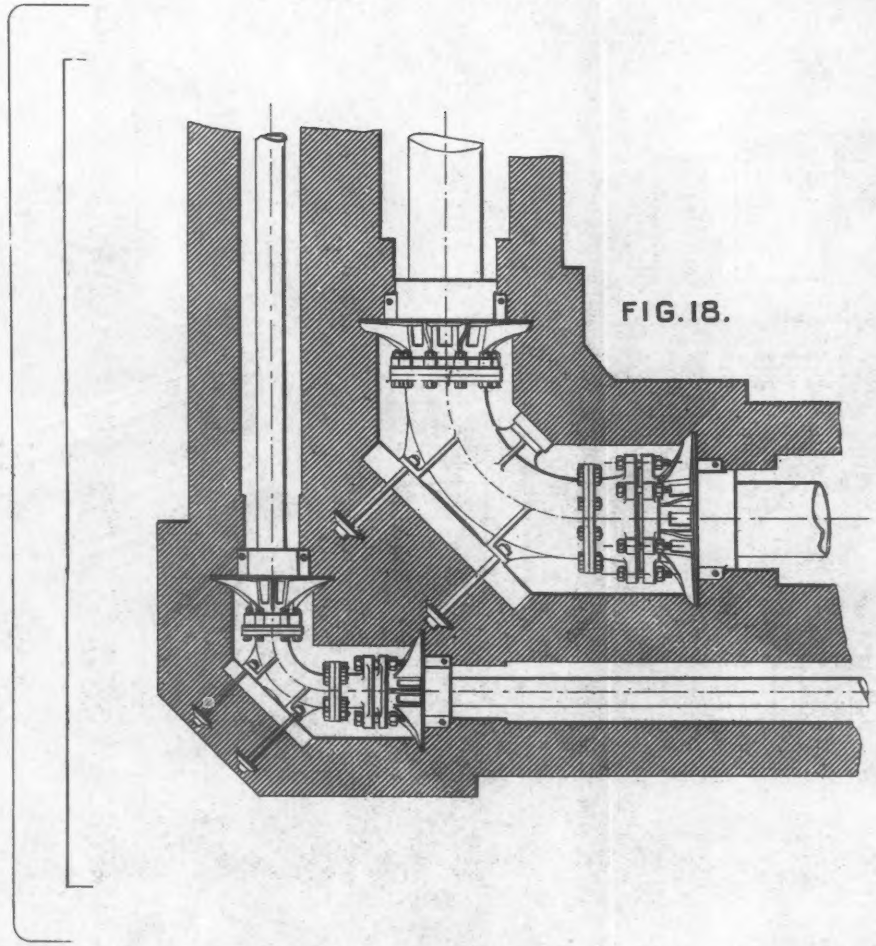


FIG. 18.

PLATE XX.
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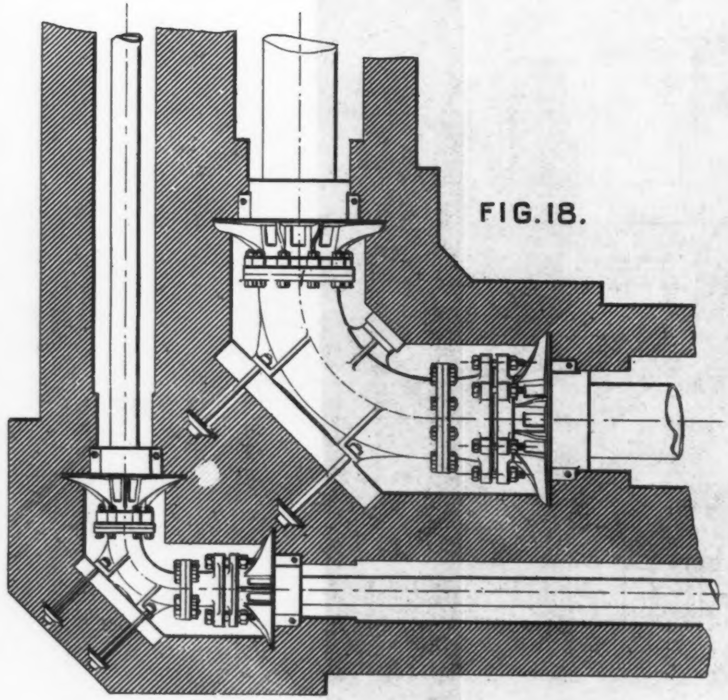

FIG. 18.

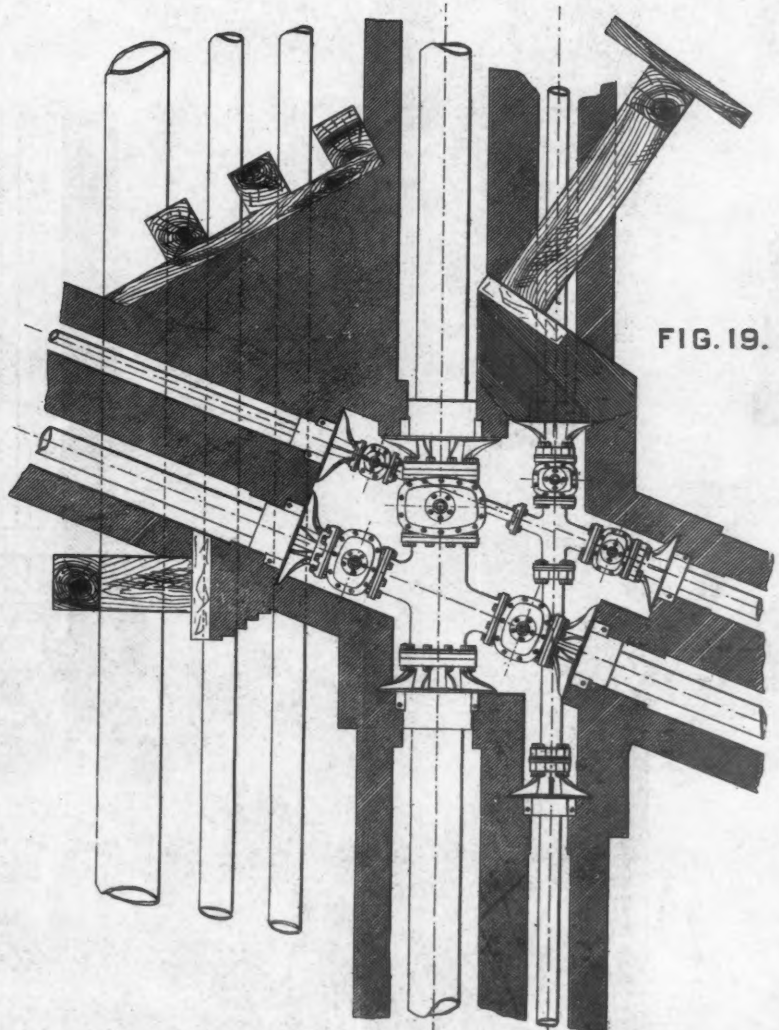

FIG. 19.

the ordinary cost of the pipes of the street plant; so that even if the smaller return pipes be made of brass, there will still be left a very excellent percentage of profit on the whole cost, due to the use of return pipes. These conditions do not apply to cheap heating plants, as explained elsewhere, so the problem whether return pipes be used must be settled by the conditions of each particular case.

The general question will naturally arise whether the district steam systems as at present developed have been sufficiently successful to warrant the construction of other plants. In response it may be stated, that there is only one class of buildings to which steam cannot be supplied at a profit from an external source, viz.: the large modern buildings, in localities where there is no legislative restriction as to the erection of steam boilers on the premises. The coal used in such buildings can in general be bought nearly as low as by a steam supply company, the same type of boiler can be used, and even if the relative price of labor is somewhat higher than at the buildings of the supply company, this only balances the profits of the latter company, so that there is no incentive for the proprietor of the building to make a change. However, it is only the largest of these buildings that have the space, and have been constructed with the foresight to enable a plant of this character to be used. In very many buildings the steam plant has been the last thing considered, and is either too small, or put in such a place that the heat from the boilers impairs the rental value of basements and other parts, so that a supply of steam from a district system will be taken if the difference in price is not too great. There is, however, another class of buildings to which the district supply is a great boom, viz.: buildings of a smaller type which have little facility for the erection of boilers, and in which the cost of attention would be comparatively high. There are a large number of these buildings in New York, which, with steam supplied from the street, have put in elevators, steam heat, and increased water distribution; and are thereby able to compete with larger buildings in the rental of comfortable and desirable offices.

The District Steam Company cannot hope to permanently supply a very large quantity of power at a particular location, except to an enterprise associated with it in a business way; but all the electric light plants will start their business by purchasing steam, and be happy to pay for continuing a connection to be used in emergencies afterward. Again, there is in every city a demand for power and heat, in small manufactories.

In New York there is a surprising number of such located in the lofts of buildings, in many of which the other floors are occupied for other business purposes. In this way ample power is obtained, in locations where the simple handling of the coal and ashes to portable engines, would make the use of the latter prohibitory. On the whole, it will be seen, then, that the steam system is a great public convenience, and the commercial question in regard to further constructions of the kind must depend upon various financial and local conditions. There can be no question but that if a large number of property owners in a given district would associate themselves together, and put up a steam plant for the improvement of their property, the enterprise would be a remunerative one, even in a business neighborhood. It is doubted, however, if in such a neighborhood the profits realized would be such as to warrant the intermediate action of promoters and large issues of stock. In a neighborhood of dwellings of well-to-do people there is, however, a very large and important field for district steam systems, particularly if the steam be simply used for heating purposes during the period heat is required, and the plant be shut down in summer, so that the operating expenses are saved. Plants of this kind pay well even in the coal regions of Pennsylvania. In the bituminous regions the residents use anthracite coal in their houses, because it is less liable to injure the furnishings by dust and smoke, whereas a district steam company can, in an out-of-the-way place, burn the slack of the bituminous coal, purchased at a little more than the price of haulage. In other cities, whether near or far from the coal regions, coal of large size and good quality is used in the furnaces and steam boilers of the wealthy and well-to-do, while a steam supply company can use fuel of a very inferior kind, purchased in quantity at a very greatly reduced cost. If, then, the steam plant be constructed cheaply, as is possible with a pressure not exceeding 40 pounds, it is believed that heating systems of this kind will pay in any dwelling neighborhood, even when the houses are widely separated, with considerable ground around each. In locations where water is cheap, water coils can be used to utilize the waste heat from the rejected water.

It is predicted that the largest use of steam will eventually be in foreign countries, where there are restrictions upon the erection of steam boilers in the city limits. In such cases the plant of the New York Steam Company would practically be duplicated (under conditions, of course,

making it possible to obtain good work). There would be both a main steam pipe capable of distributing steam at high pressure and a return pipe, so that the hot water and steam would be kept out of the sewers. Such a plant, for reasons above stated, would add greatly to the value of property along the line, and the prices which would be obtained would insure a good interest on the investment. It would be entirely practicable in some cities to carry out a plan proposed for San Francisco, to wit, to use high steam pressure in the manufacturing and office neighborhoods, discharge the exhaust steam into other steam mains, and conduct the same to dwelling neighborhoods in the vicinity, for heating purposes, from which the return water would either be discharged into the sewers at a low temperature under proper supervision, or if water was high priced, be returned to the station.

(The discussion on this paper was taken with the one by Mr. Worthen which follows.)

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

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STEAM HEATING.

By WM. E. WORTHEN, Past President, Am. Soc. C. E.

WITH DISCUSSION.

I have thought that it might be interesting to the members of this Society to give as a sort of supplement to the paper read by Dr. Emery, on "Steam Heating," an outline of the history of heating as applied to the heating of the cotton mills at Lowell. My early life was passed there, from its first inception as a manufacturing center in 1822, up to 1849, and I had especial opportunities as a boy in going over the mills, and afterward as an engineer in their construction.

The earliest cotton mills were heated by hot-air furnaces, one at each end of the mills. The mills were about 150 feet long by 50 feet wide, with furnaces at each end as shown in Fig. 2, Plate XXI, with brick flues opening into each story. The furnaces were cast-iron boxes with corrugated top and sides cast in one piece, and of length to admit cordwood of the usual 4-foot lengths without sawing. The furnaces were enclosed in small brick buildings, arched over in brick, and to protect the mortar joints of this arch from the weather it was covered with sheet lead. As the lead expanded from the heat beneath and from the sun, it hung down from the eaves in fringes, and as it had not cohesive strength to draw the fringes back in cooling, they hung there till cut off from time to time. Eventually the lead

parted at the ridge, like many financial schemes in which the construction account is kept open, declaring dividends from apparent surplus, with at last a central burst at the ridge.

Hot-air furnaces with brick flues were put into the houses of the mill agents, and the first church, consecrated in 1824, was an example of a closed hot-air circulation. The furnace was placed beneath the center of the church with the usual hot-air chamber of brick. The cold-air duct drew from the end of the church, just inside of the doors, and the hot air was delivered into the center through an aperture directly above the furnace.

At this time wood was the only fuel. Steam was introduced about 1836, boilers were placed in the old hot-air furnace houses, and the steam-pipes were 3 to 6 inches of cast-iron suspended from the ceilings, the steam and drip connections being of small wrought-iron pipe. It has been very difficult to find out when wrought-iron pipe was first introduced. I understand from Morris, Tasker & Co., that "the butt welded pipe was first made in this country about the year 1830 to 1832." In the early editions of Appleton's "Dictionary of Mechanics," under the head of forging, it says: "Musket barrels, when made entirely by hand, were forged in the form of long strips about a yard long and 4 inches wide but taper both in length and width, which were bent round a cylindrical mandrel until their edges slightly overlapped; they were then welded at three or four heats, by introducing a mandrel within them instantly on their removal from the fire."

When the illumination by gas was at first introduced in the large way, by Aaron Manby, Esq., then of the Horsley Iron Works, England, old musket barrels were employed for the conveyance of gas. The breech ends of the musket barrels were broached and tapped, and the muzzles were screwed externally, to connect the two without detached sockets. From the rapid increase of gas illumination, old gun barrels soon became scarce; this led to a series of valuable contrivances for the manufacture of the wrought-iron tubes, commencing with Russel's patent in 1824, under which the tubes were first bent up by hand hammers and swages to bring the edges near together. They were then welded between semi-circular swages, fixed respectively in the anvil, and the face of a small tilt-hammer worked by machinery, by a series of blows along the tube, either with or without mandrel. The tube was completed by being passed between rollers with half-round grooves, which forced it over a conical

or egg-shaped piece at the end of a long bar, to perfect the interior surface.

In a communication in 1882, of the late Robert Briggs, M. Am. Soc. C. E., to the Institution of Civil Engineers, of which he was also a member, it is stated that the late Joseph Nason, of Boston and New York, was the originator, improver, and adapter of much that is essential and now implicitly followed, in the general arrangement and details of the apparatus employed in the American practice of heating buildings by steam. I knew Mr. Nason very well, and recollect about 1840, when a very young man, he returned from England and endeavored to introduce Perkins's system of heating by hot water circulation through small pipes. He attempted to heat one of the dye kettles of the Merrimack Print Works in this way, but did not succeed. He put hot water apparatus into the houses of some of the agents of the mills which worked well. He soon turned his attention to steam heating, with the results as given above by Mr. Briggs. With regard to the Perkins system of heating with hot water, in the *Journal of the Franklin Institute* for September, 1837, is the following quotation from a letter from Jacob Perkins written in 1836: "My son Anger is doing well with his patented apparatus for heating by hot water. The system of heating by hot water and steam is being abandoned, and the old apparatus removed from various public buildings to give place to the new. This is the case in the British Museum, where Anger has given great satisfaction. It would seem incredible, but it is a fact, that in this apparatus a stream of hot water which is not thicker than your little finger, carries the heat 700 feet, and then returns to the boiler at a temperature of 100 degrees. The boiler is a coil of tubes of the same diameter with the conducting pipe."

The steam-pipes, as placed in the mills by Mr. Nason, were arranged along the inside of the wall and were, I think, at first trombone coils, that is, the circulation was through a single pipe returning by a single half-turn or return bends, and so continuously from one end to another according to the number of pipes required. Afterward branch tees or manifolds were introduced, expansion being provided for by right-angled bends in the pipes at the end of the room; afterward these bends were turned up vertically, making mitre branches with the horizontal lines.

At present the Boston Manufacturers' Mutual Fire Insurance Com-

pany recommend the placing of the coils of steam pipes for heating purposes overhead in mills, in almost all cases.

When the heat was first introduced to heat the mills, as said before, the small hot-air furnace buildings were used as boiler houses. The boilers themselves were vertical, and were fired by watchmen who had many other duties. They carried thick fires, and the feed-water was supplied automatically by balanced stone floats, which drew water from cisterns in the attic of the mills, supplied by three and five throw single plunger pumps driven by water wheels. These pumps and cisterns were also used for mill and fire service.

The form of the old boilers has passed out of remembrance, but I give a section of one, Fig. 4, Plate XXI, introduced by James B. Francis, Past President Am. Soc. C. E.; and the results of experiments made by him in 1841 on the evaporation of two boilers used for heating the Massachusetts Cotton Mill No. 2.

Area of grate surface in each boiler...	3.20	square feet.
Area of fire surface....................	126.50	"
Duration of experiment...............	115.52	hours.
Total number of pounds of coal burned	5 283	pounds.
Total number of pounds of water evaporated 866×62.375................	54 016.75	"
Temperature of feed water............	32	degrees.
Pounds of water evaporated from one pound of coal from initial temperature $\frac{54\ 016.75}{5\ 283}$	10.225	pounds.
Pounds of water evaporated from one pound of coal from 212 degrees $\frac{180 + 1\ 000}{1\ 000} \times 10.225$	12.065	"
Pounds of coal burned per hour on one square foot of grate surface $\frac{5\ 283}{2 \times 3.2 \times 115.52}$	7.146	"
Pounds of coal burned per hour to each square foot of fire surface $\frac{5\ 283}{2 \times 126.5 \times 115.52}$	0.181	"
Square feet of fire surface to one square foot of grate surface..............	39.53	"

The above was given me by Mr. Francis many years since, and I have preserved it as an example of excellent practice, simple in construction, and economical in results; and my opinion has not changed after testing many and varied forms of boiler. Mr. Francis now writes me of the results of two other trials of one hundred and twenty hours each:

"February 22d to 27th, 1841. 10 245 pounds of water evaporated by 1 pound of coal.

"February 15th to 20th, 1841. 9 917 pounds of water evaporated by 1 pound of coal."

The temperature of water supplied to the boiler is not given, but it could not have been much above 32 degrees.

Before 1840 the mills had a nearly stereotyped form and size, but soon after, the capacity of the mills as to machinery and product began to be increased, and at the present time the Manville Cotton Mill No. 2, Plate XXI, Manville, R. I., is probably as large as any. It is 783 feet long by 98 feet wide, and four stories above basement, 120 000 spindles. The illustration, Figs. 2 and 3, shows relative size of this and an old Lowell mill, and the location of the boilers. With the first increase of size of mills at Lowell, the spaces between the mills were utilized, supplementary steam-engines were introduced (the first one under my charge at the Hamilton Mills in 1845), and the boilers for steam heating and power were concentrated in one building, and put into the hands of efficient stokers. This arrangement obtained at Printing and Dye Works earlier.

In my address at Kaaterskill I alluded to a report made by me in 1866, to the Merrimack Manufacturing Company, of Lowell, on the economy of using high steam for power at the cotton-mills; and afterward the exhaust at their print works for the purposes of heating, boiling, etc.; and suggested passing the steam through engines of 1 200 horse-power, and using the exhaust steam afterward in the print works, with a back pressure of about 6 pounds. I also stated that the amount of coal properly chargeable to power in this case would not exceed 1 pound of coal per horse-power per hour. It was a success, and of its present extent the superintendent of the works writes me as follows: "We have only one pair (34 × 72 inches) condensing engines on our premises, all the others (something over a hundred cylinders) exhaust into a system of mains, from which we draw all the heat we require. What we do not require for heat we take into the condensing cylinders before mentioned, and reconvert into power."

E. D. Leavitt made a test of this steam plant and furnishes the following interesting results: "Three trials were made in 1877, two of which were of the cotton yard plant, and one of the print yard machinery. All the steam made by the boilers tested was passed through the engines. The trial was extended over a period of one week. One engine of the cotton yard plant was run condensing, and one non-condensing. In the first trial, extending from August 27th to September 1st, inclusive, four of the vertical Corliss boilers were used; in the second trial, but three were used, the intent being to determine the potential evaporation of the boilers.

The total amount of coal used on the first trial was..................	181 574.9 pounds.
The total amount of coal used on the second trial was................	196 082.0 "
The total amount of water evaporated on the first trial was.......	1 508 929.33 "
The total amount of water evaporated on the second trial was..........	1 628 496.56 "
The amount of grate surface on the first trial was......................	413.08 square feet.
The amount of grate surface on the second trial was.................	309.81 "
The amount of heating surface on the first trial was...................	15 826.28 "
The amount of heating surface on the second trial was.................	11 869.71 "
Gross combustion per square foot of grate on first trial was..........	7.326 pounds.
Gross combustion per square foot of grate on second trial was.........	10.54 "
Coal consumed per 1 horse-power per hour by condensing engine, first trial...........................	2.3289 "
Coal consumed per 1 horse-power per hour by condensing engine, second trial...........................	2.4115 "
Coal consumed per 1 horse-power per hour by non-condensing, first trial.	3.5348 "

Coal consumed per 1 horse-power per hour by non-condensing, second trial..............................	3.7700 pounds.
Deducting all heat supplied for dyeing, heating and boiling by the exhaust of the non-condensing engine, the amount of net coal per 1 horse-power per hour becomes on first trial......................	.67817 "
Deducting all heat supplied for dyeing, heating and boiling by the exhaust of the non-condensing engine, the amount of net coal per 1 horse-power per hour becomes on second trial..................	.5816 "

It was estimated that the mill power per day with the condensing engine, cost on the first trial.....	$6 58
It was estimated that the mill power per day with the condensing engine, cost on the second trial.	6 74
Cost of mill power per day with the non-condensing engine on the first trial........................	1 77
Cost of mill power per day with the non-condensing engine on the second trial......................	1 56

The difference being due to the value of the exhaust of the non-condensing engine for boiling and heating."

In a late letter the following explanation was given of the methods of conducting and analyzing the experiments: "We took, in each test of one week, over one thousand indicator cards, all of which were computed for volumes. The total coal consumed in the trial was then divided, in proportion to the volume of steam exhausted by the condensing and non-condensing cylinders, and the coal per 1 horse-power per hour was computed on this basis, being for the non-condensing engine 3.5348 pounds per horse-power per hour, and 2.3289 pounds per horse-power per hour for the condensing engine." "All the steam used by the non-condensing cylinder, less that used for conversion into work, was available for heating and dyeing. Adding this less amount to the coal consumed by the condensing engine,

and dividing by the total indicated horse-power, is what gave the true result of coal per horse-power per hour. In the estimate of the cost per mill-power by condensing and non-condensing engines, we took the interest on the cost of the plant, wages and supplies; but inasmuch as the boiler plant would have to be maintained and the employees be practically the same whether the engines were there or not, for supplying the dyeing-house and drying-rooms, the wage account for the non condensing engine became very small."

A mill-power at the Merrimack mills is 25 cubic feet of water per second on a 30-foot fall. Allowing a loss of head and fall of 1 foot for getting the water to and from the wheel, the net fall will be 29 feet.

$$\frac{\text{25 cubic feet water per second x 62.4 weight per cubic foot x 29-foot fall}}{550} = \text{82.24 h.-p., gross.}$$

Estimating the percentage of effect of the water on the wheel at 80, $82.28 \times 80 = 65.79$ horse-power, net. It is usual to consider a mill-power 65 horse-power effective. In this connection I give a simple rule for estimating the net horse-power of a water-power: It is to multiply the effective fall by the flow per second in cubic feet, and divide the product by 11. Example: $\frac{\text{29 feet x 25 cubic feet}}{11} = 65.9$ horse-power.

From Mr. Leavitt's paper above we obtain:

Estimated mill-power per day with condensing engine, cost on the first trial	\$6 58
Estimated mill-power per day with condensing engine, cost on the second trial	6 74
The average $= \frac{13.32}{2}$, and $\frac{6.66}{65}$ gives a cost per day per horse-power of	10.2 cents.
Estimated mill-power per day with non-condensing engine, cost on the first trial	\$1 77
Estimated mill-power per day with non-condensing engine, cost on the second trial	1 56
The average $= \frac{3.33}{2}$, and $\frac{1.665}{65}$ gives a cost per day per horse-power of	2.55 cents,

or say ten cents per day of ten hours per horse-power for condensing engine; or say two and one-half cents per day of ten hours per horse-power for non-condensing engine. As this steam-plant is of great interest to the profession, I have, through Mr. Francis and Mr. Ludlam, the Super

intendent of the mills obtained a plan of the works, Fig. 1, Plate XXI, showing the position of steam and exhaust-pipes. The smaller steam-engines are not marked in the plan; they all draw from one steam-pipe and exhaust into another pipe. The following is the schedule furnished me:

IN THE COTTON YARD.

One condensing engine, nominally about 1 300 horse-power, but usually running one cylinder only, giving about	400 horse-power.
One high-pressure engine, nominally 1 200 horse-power, usually running............	600 "
One Buckeye pressure engine................	500 "

The high-pressure engines exhaust into a system of pipes, extending over both cotton and print yards, carrying 8 or 9 pounds pressure. Usually about 25 per cent. of the steam goes to the print yard. All the heating and dressing in the cotton yard is supplied from the balance.

IN THE PRINT YARD.

All the engines are non-condensing, and exhaust into the general system of low-pressure pipes.

One engine................................	350 horse-power.
One engine................................	150 "
One Buckeye engine for electric lighting	150 "
Twenty engines running printing machines, called 15 horse-power each................	300 "
Ten other small engines, called 10 horse-power each	100 "

All the steam is supplied from one boiler-house, pressure in boilers 85 pounds per square inch. There are but two common stuffing-box expansion-joints on the straight parts of the steam, and none on the exhaust-pipes. Expansion is met by the bends in the pipes, the pipes are protected by the Ober Steam Jacket, which consists of a covering of paper, wood or iron, supported on a flexible metallic frame, which gives the required space for mineral wool or other packing, the whole being securely bound together by metallic bands.

It will be seen from Mr. Leavitt's results, and the practical operation of the steam plant at the Merrimack Mills for a long term of years, and still in use, that if such a plant could be arranged in a city for power and

heating, it would result in great reduction of fuel, with all the economies expected to be secured by central steam-heating plants. The great difficulty of carrying out such an arrangement of steam and exhaust pipes, is to secure a good position for them. By all experience, it has been demonstrated that steam-pipes should be easy of access. In the later progress of the work of the American Steam Heating Company, I was called in as consulting engineer, and gave my advice to make tunnels at a low grade just above tide, so as not to interfere with water, gas or sewer pipes, that no disturbance of the streets would be necessary for their construction, or for their connections; that in the lower part of the city, where the strata is sand, a pipe either of wood or iron, of sufficient section to contain steam and exhaust pipes, could be readily forced through from the tunnel to the building requiring steam, as I had myself done; and in rock, the diamond drill would readily drive proper holes. It is evident that if this had been done, the Merrimack Mills arrangement could have been readily carried out. Unfortunately funds were falling off and the company could not adopt my advice. I suggested that this tunnel should be of a capacity for high-pressure water pipes which we very much need, for gas mains, and for electric wires, connections to be made similarly to those proposed for steam. Later I devised a viaduct 70 feet high for the same purpose, and Mr. T. Cooper, M. Am. Soc. C. E., kindly made a sketch of a form of construction, and estimated the cost. It has not been built.

Of the great convenience of water mains on the roofs of the houses, there is no doubt. It is recommended by the N. E. Mutual Fire Insurance Companies; the head is always maintained, and it controls the stories inaccessible from the usual water mains. This makes it also valuable for all domestic and building service. Should rapid transit ever develop into rails of such an elevated location, arrangements should be made in connection with them for steam, water, gas, and electric service, and with the present elevated railroads, the vacant space between the trusses could be advantageously used for these purposes.

In the section of the stone boiler float, which was made from memory, the water-line is about the center of the float (see Fig. 5, Plate XXI). No provision was made for balancing the area of the rod or stem of the float, and the water-line varied on that account. There was probably a stuffing-box, but this I judge unnecessary, as I had a plunger steam indicator of $\frac{3}{8}$ of an inch diameter which moved readily and was steam

tight under a pressure of 200 pounds to the inch. It would be possible to make the stem of the stone float $\frac{1}{8}$ of an inch diameter in like manner, and the consequent variation of water-line under variation of pressure would be unimportant.

In answer to the question whether the condensed water in the exhaust pipe was used at the Merrimack Mills, Mr. Francis writes me "All the condensed water from all the mills and the print works, except from the low-pressure engine and what necessarily remains in the kettles, etc., in which water is heated by admitting steam, is carried back to the boiler-house, when it is pumped through a "Green Economizer," where it is heated up to about 150 degrees and used for feed-water.

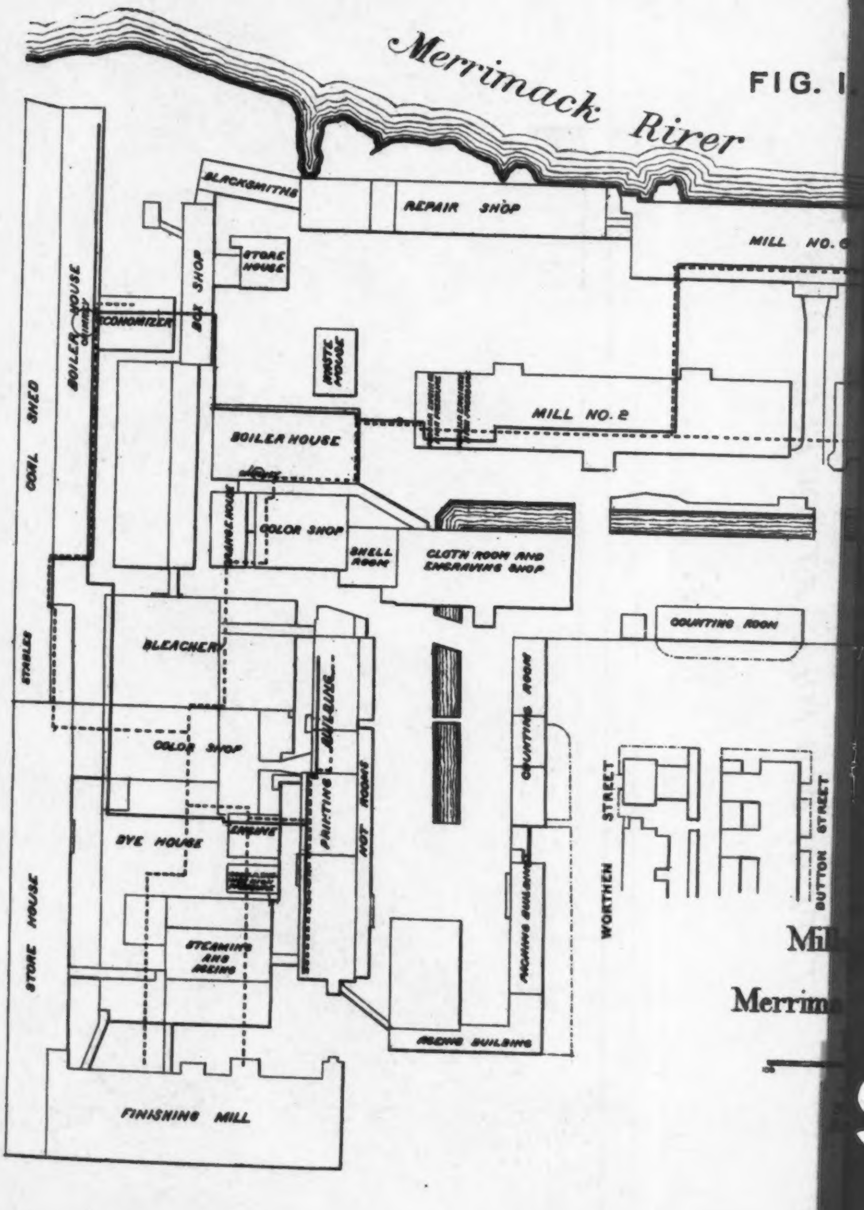
DISCUSSION.

James B. Francis, Past President Am. Soc. C. E.—The arrangements of the Merrimack Company have been entirely satisfactory. The mills are run by water and steam power together. They find great economy in using non-condensing engines. In the Cotton mills, where heat is required, no steam is drawn directly from the boilers for heating purposes, but the exhaust from the engines is used. Practically, the power is all clear gain so far as the fuel is concerned. The exhaust is made under a back pressure of about 8 lbs. to the square inch into a system of low-pressure pipes, 6 inches to 18 inches in diameter, which extend over the works, and from which steam for heating is drawn at any point where it is needed. There is a loss in carrying the steam, of perhaps 3 or 4 pounds to the square inch (about 4 pounds the man in charge told me) at the point most distant from the engines; so that there seems to be no difficulty in distributing the heat in the pipes, if you do not undertake to do it on too big a scale at once. This property covers about 20 acres.

The non-conducting material covering the pipes to prevent condensation is really mineral wool, which is a kind of glass, spun in very fine threads, protected by a woolen covering on the outside. A photograph taken in winter for the purpose, shows the snow and ice laying upon the pipe, thus indicating very little loss of heat.

The water of condensation is collected in a system of pipes extending over the works and returned to the boiler-house by gravity, where it is pumped back into the boilers, the pipes passing through a Green economizer, where it is heated to near the temperature in the boilers.

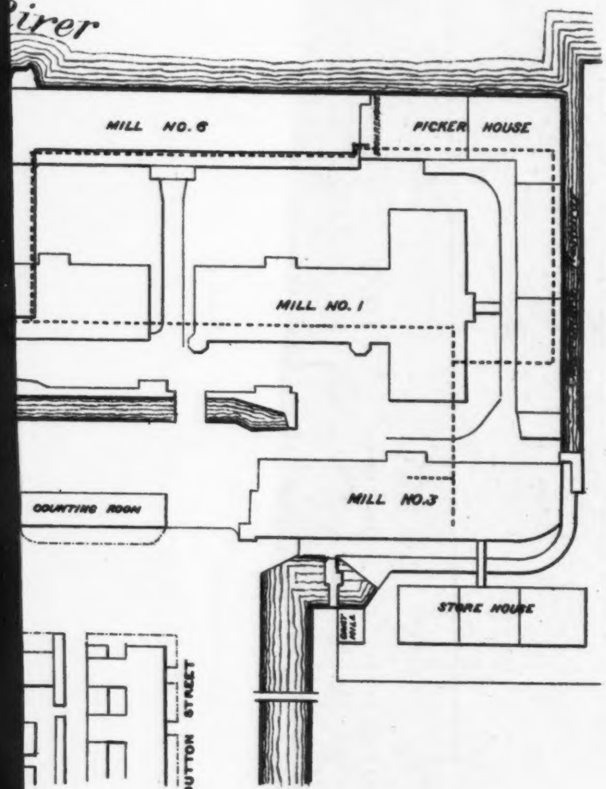
FIG. 1.



Mill

Merrim

FIG. I.



Mills and Print Works
OF THE
Merrimack Manufacturing Co.
Lowell, Mass.

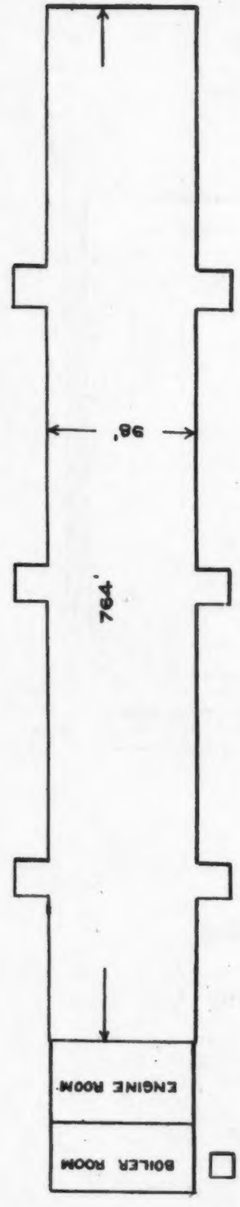


FIG. 2. MANVILLE MILL RHODE ISLAND

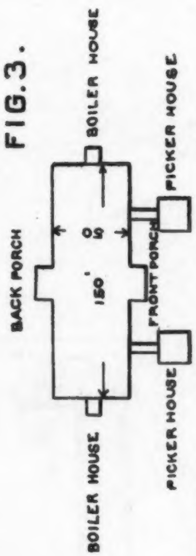


FIG. 3. TYPE OF OLD MILL AT LOWELL, MASS.

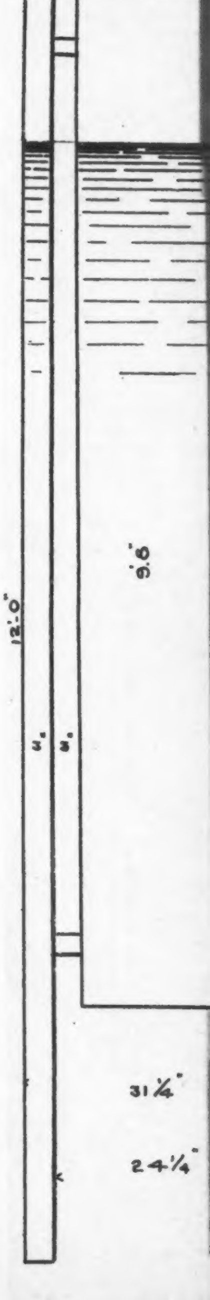


PLATE XXI.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXIV. No 467.
WORTHEN ON
STEAM HEAT.

FIG. 2.

MANVILLE MILL RHODE ISLAND

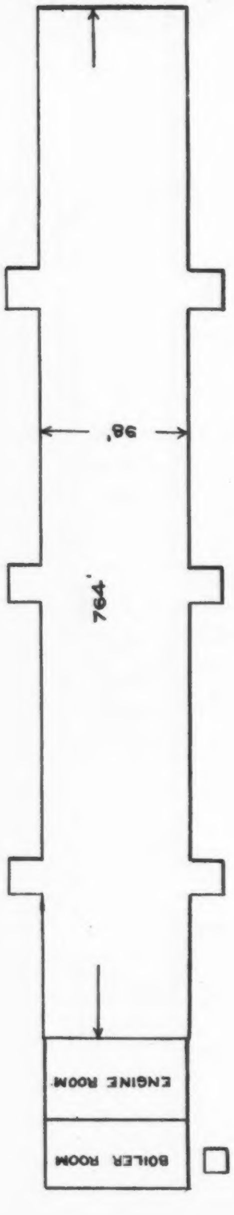
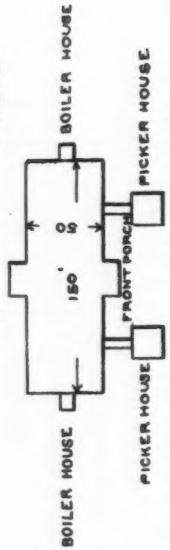


FIG. 3.



TYPE OF OLD MILL AT LOWELL, MASS.

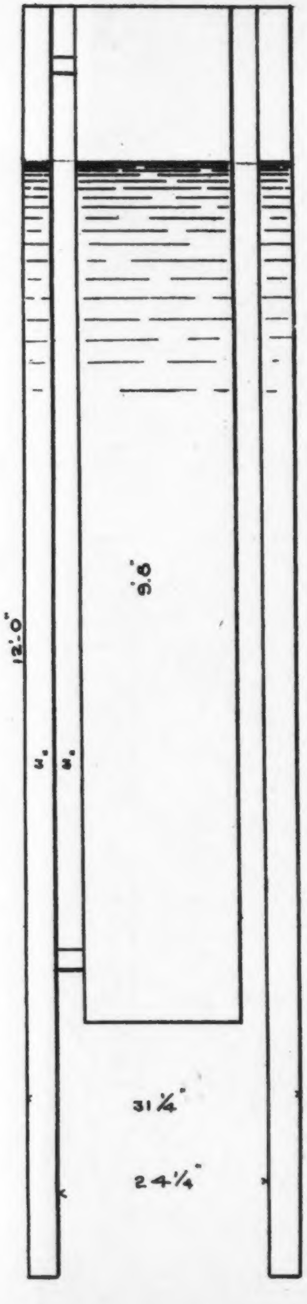
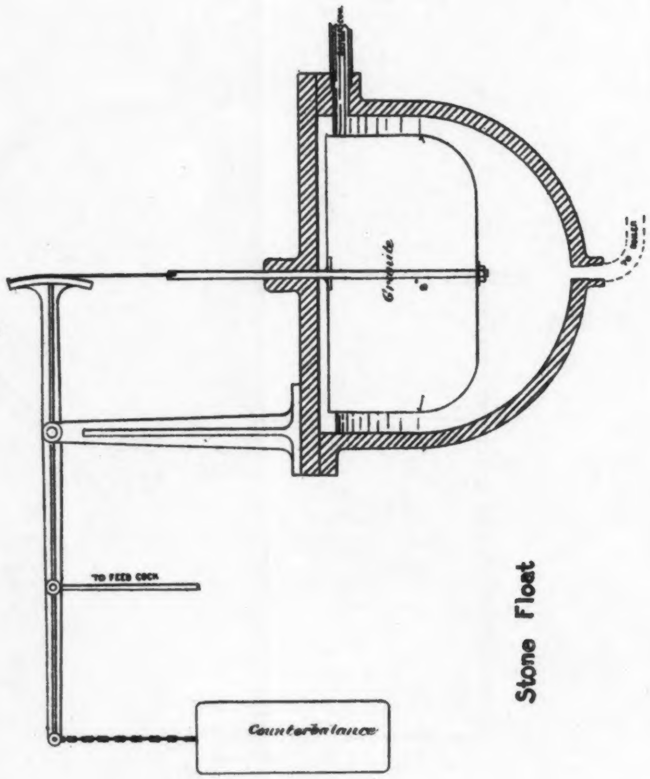


FIG. 4.

FIG. 5.



Stone Float

Charles E. Emery, M. Am. Soc. C. E.—I am very much gratified that my paper has been the means of bringing out a statement of the experience, in the same general direction, of one we have known and respected for years. Steam heating, considered simply as a business, has been practiced with some measure of success by every steam-fitter throughout the country, but such business is really founded on scientific principles worthy the efforts of engineers of talent who have had the best opportunities. This is shown by the results accomplished by the author of the paper and his associates, long before steam-fitting as a business became established, and it will be seen that recent efforts are but modifications of the developments so thoroughly worked out years ago in the Eastern mills. The paper is a valuable contribution to the records of the Society, and I trust may have the effect to induce others to state their experience in this and other lines.

The suggestions in the paper are in part being carried out. There are many buildings in large cities which are heated entirely by exhaust steam, and in a very few cases the surplus is distributed to adjoining buildings. It has been suggested to connect the exhaust pipes of the engines of various establishments to a street main, and distribute the steam exactly as was done in this mill. The idea has been previously suggested, and was carried out in the steam plant at Lynn, which failed for financial reasons connected with the organization of the company. A plan has been worked out in detail, to collect the exhaust steam from the engines in the business districts of San Francisco, and conduct it to the closely adjacent resident district, but the scheme has not yet received sufficient financial support. Such a system is not generally applicable, on account of the multiplicity of connections. In a large city, it is undesirable to waste the water of condensation from heating coils; first, on account of the value of the water itself; second, on account of the heat it contains; and third, on account of the inevitable nuisance arising from discharging hot water into the sewers. With proper water coils, little more than tepid water should be discharged, but in cities many users do not have the space, and many that could arrange that feature are not inclined, on account of the cost, to provide such coils, so that water at a high temperature, which will discharge a considerable percentage of steam in cooling, is admitted to the sewers, to the injury of the brickwork and the discomfort of the public. It follows, then, that a proper exhaust system must have three pipes; first, the main steam-pipe; second, the low-pressure or exhaust-pipe to supply steam for heat, and third, a return water pipe. This makes the number of connections so great that the system is not practicable, except where the location is particularly adapted to its use. In 1882, when connecting a large electric-light plant in Fulton street to the mains of the New York Steam Company, a section of a large main was laid with outlet to receive the exhaust from the engines, but no exhaust connections were made, as other work demanded imme-

diate attention, and the buildings in that particular vicinity were occupied by a large number of small tenants, so that there was no unanimity of action in taking steam for heating purposes. In San Francisco the manufacturing and business district is so well defined, and yet located so near a well defined resident district, that the plan is particularly applicable.

In the introduction of exhaust steam for heating, it was realized that the mains must be larger than when steam of higher pressure is circulated, so that the system appeared to be limited to new buildings, or those in which steam pipes were applied for the first time. This difficulty has been overcome, comparatively recently, by the connection of an air-pump to the lower end of the return-pipes, so as to produce a partial vacuum and induce a current in that direction, even when the steam for heating was supplied at a comparatively low pressure from the exhaust of steam-engines. In some cases the air-pump is supplemented with a condenser which reduces the amount of vapor to be handled. This device should not be necessary when the return-pipes are so arranged as to act as heating surface.

Mr. William J. Baldwin, M. Am. Soc. C. E.—There is danger from grease being carried into the boilers whenever the exhaust steam of an engine is used for heating purposes. The exhaust steam is sent through the building, condensed, and returned to a tank and pumped from the tank into the boilers. This has been the custom in a great many places, and forms an element of danger to the boilers. In the Massachusetts Institute of Technology, they made no provision at first for separating the grease from the exhaust steam and carried it (the grease) into the boilers, and ruined all the boilers. The same thing is often done in New York; there are some buildings that have special provisions for removing the grease, and lately there have been several patents for separating grease from the exhaust steam. Such an apparatus is shown in Fig. 6. When the steam leaves the engine it is carried through the pipe *a* into the tank, and projected into the water in the tank *T*. The water and grease are directed against the water already in the tank, and a great deal of grease is taken up at once, then the comparatively clean steam passes on through the pipe *b* into the boilers. There is such an apparatus in the Manhattan Company's Bank in Wall street, which has been in use about five years, and you will find no oil in the receiving-tank.

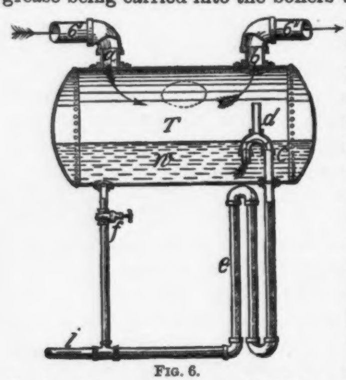


Fig. 6.

Mr. WORTHEN.—I think the one in the Equitable Assurance Company's building was very successful; it had a blow-off on the top.

A MEMBER.—There is one in the Stewart building that takes four large distributing-mains from different parts of the building.

FRANK W. SKINNER, M. Am. Soc. C. E.—What is the condition of the return-pipes of the mills, with regard to corrosion; do they suffer seriously from it?

Mr. FRANCIS.—I cannot say, from my own experience, but it is generally understood that wrought-iron pipes carrying warm water, rust badly.

Mr. WORTHEN.—The water at about 120° Fahr. bites into the pipe very strongly, but above or below this it does not affect it.

W. HOWARD WHITE, M. Am. Soc. C. E.—I had a little experience bearing on the last question. Some years ago, for the Chicago, Burlington and Quincy road, at Burlington, Iowa, we heated the depot from a round-house about 1 500 feet away. The calculation made at the time, showed that the saving by returning the water to the boiler would not be sufficient to pay for the extra cost of the return-pipe, so we left that out and discharged the water. Afterward I saw the Master Mechanic of the road and he told me that the steam-pipe had been corroded by the water. It was attributed to the want of a return-pipe. He thought if the water had been returned, having only the same amount of acid which had been neutralized by its first passage through the pipes, the corrosion would not have occurred; I had no opportunity of knowing how correct his theory was. At the shops of the company outside of town the water was all returned, but I do not remember asking him whether they found it a great advantage. The inquiry would have been somewhat vitiated, too, because at that point we had different water.

Mr. H. W. BRINCKERHOFF, M. Am. Soc. C. E.—A very intelligent man who had put in a great deal of the old-fashioned hot water apparatus, without an expansion tank, once told me he had worked up to pressures as high as 1 200 pounds per square inch, and added that he had seen the flowpipe from the boiler visibly red in the dark; in other words, the water was red-hot. I was rather inclined to think that he might be correct, incredible as it seemed, because, on looking up the matter, I found that steam at 1 200 pounds per square inch has very closely the temperature of iron at a red heat in the dark. Besides, I was influenced by the example of a very polite Frenchman, who, after listening to a story related by a friend, said: "If you say you have seen it, I will believe it, but I would not believe it if I had seen it myself."

Mr. WORTHEN.—You will find in Perkins's treatise on hot water, he states as a particular fact, that the pipes get red-hot.

Mr. BALDWIN.—Mr. Perkins provides an expansion tank; he expands

into the tank all the steam that is formed, so that the pressure on the water in the apparatus is elastic, the circulation goes on below it.

Mr. Worthen.—Suppose it did not circulate, would it get red-hot?

Mr. Baldwin.—Yes, sir.

Mr. Emery.—There is another point which, I think, should go on record in this connection, viz: the practice in some cotton mills. In moderate sized mills of a few thousand spindles, but a small portion of the exhaust steam is required for heating. The engines are generally double, and connected to the opposite ends of the engine shaft. With these Mr. Corliss adopted the plan of exhausting one end only of one cylinder to a low-pressure steampipe, and exhausting the other end of the same cylinder and both ends of the other cylinder to the condenser; thereby obtaining for three-quarters of the engine-power the economy of a condensing engine, and utilizing the steam for the other one-quarter, first, for power, and afterward to supply the low-pressure steam required in the mill for heating, "slashing" and similar purposes.

Mr. H. W. Brinckerhoff.—I would like to ask if anybody here has seen anything of the practical working of what is called the steam loop; it was illustrated in *Engineering News*, and has been on exhibition in Cortlandt street. I have never seen it in operation myself, and thought if any one knew of its working, it would be interesting to have it described. It is something like the sketch shown in Fig. 7.

A is a steam boiler from whose dome, *B*, steam is taken in the usual way through pipe *D* to, say a system of heating pipes represented by the radiator or flat coil *E*, from whose lowest point *F*, a pipe, *GHI*, leads back to the boiler, which it enters below the water line. The apparatus is designed to return the condensed water to the boiler from a point below the water line, without a trap or any moving parts, and is said to operate as follows: Steam having been raised in the boiler, the valves *C* and *O* are opened, and steam blown through all the pipes to clear them of air. Valve *O* is then closed, and the steam condenses in the vertical pipe

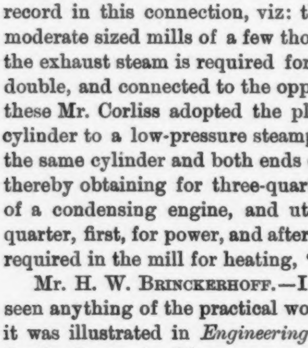


Fig. 7.

I until it reaches a height, say *M*, sufficiently above the water-line at *N* to make up for the diminished pressure in the heating system, and, with its assistance, to overcome the pressure in the boiler and flow into it through the check valve *L*. This action, once started, is said to be continuous and rapid, the water accumulating at *F* being swept through pipes *G* and *H* in the form of spray, or carried through them in plugs or short pistons, alternating with small quantities of steam which is con-

densed in the pipe *H*. This pipe is slightly inclined toward the boiler, so that all the water which reaches it flows on to the boiler. The theory of this action is, that the weight of the water in pipe *I* is always enough greater than that of the detached plugs in pipe *G* to more than make up for the difference between the pressures at *L* and *F*, and so flows into the boiler against its pressure. The steam which separates the plugs of water in pipe *G*, and thus makes them collectively lighter than the water in pipe *I*, disappears by condensation in pipe *H*; and thus the action becomes continuous. The only office of check valve *L* appears to be, to prevent the water in the boiler from blowing off when valve *O* is opened to blow through.

The explanation seems reasonable, and the apparatus is said to be rapidly coming into use; but its action is so contrary to what would at first glance be expected, that I thought it would be interesting to hear more about it from the possible experience of some one present.

Mr. Emery.—There is no doubt but that the steam loop operates satisfactorily. It is practically a simple, and an inverted siphon; the latter connected to the place to be drained, the former provided with a long pipe or condensing tube at the top. As water collects in the inverted siphon the steam in the regular siphon partially condenses, and the water in the former is carried up into the horizontal pipe of the latter to supply the vacuum, and running down gradually fills up the portion corresponding to the long leg, in due time accumulating sufficient head in connection with the pressure, to raise the check valve and enter the boiler. A continual series of partial condensations and restorations of pressure, carry the water from the inverted siphon over into the long leg of the simple siphon, and the apparatus works reliably when once started. I have used the same principle in draining steam mains in New York. Where it was impracticable to put a trap below the mains, I erected it in a box under the edge of the sidewalk. The water was lifted to the trap in the same way as in the steam loop, and when sufficient was brought up to fill the bucket, the trap valve opened and the pressure blew it out to the return main. You will observe one of these boxes in the sidewalk on Wall street, near Nassau street, and nearly in front of the Sub-Treasury building.

Mr. Worthen.—This reminds me of an experience I had. I was building a machine shop and put steam-engines on every floor and exhausted into a single pipe. The steam condensed and did not blow out except in clots. The exhaust pipe was 6 inches in diameter, and large enough for the engines, but the condensed water clogged in the pipe till the obstruction was so great that it was blown out with great force and in pails-full.

Mr. Emery.—I had the same difficulty with a steam-pipe working under considerable pressure. The 10-inch main on Madison avenue from 58th street north, ran up a rather stiff grade, sufficient it was supposed to

carry the water of condensation in the pipe, back under the current of steam moving up the hill to a trap at the foot of the hill. In practice, however, at least with but few buildings connected on the line and in the side streets, the current of steam up the hill was sufficient to hold back the water, and in some of the houses near the end of the line there would be a flow of steam for a time, when suddenly the whole system would become surcharged with water, until the pipe was drained at the top of the hill instead of the bottom. The difficulty was prevented by putting in two traps at different points along the slope, which delivered to the return main any water brought to them down the hill by gravity, or up the hill by the entraining action of the steam, thus preventing sufficient accumulations to form a plug of water to be carried into the buildings.

The CHAIR.—I understood Mr. Worthen to say he had made a great many connections from the street into the houses, by forcing the pipes through.

Mr. WORTHEN.—I did not say a great many, I said I had made them. Some steam heating companies make those connections now. At one time I had a boiler in Catharine lane, and my steam pipes were in the cellar, inside of the building into which I dug down to get room enough for the steam heater; then I had to get the steam into it and return the water. I took a piece of southern pine and made a box of about 4 inches inside diameter. I think I made it in two pieces. I laid it down and put a jack-screw behind it and had a spoon with which I removed the sand from the interior, and thus forced the box through, passing entirely under the foundation walls. It has been done a great many times since in that way without disturbing paving or roadway.

Mr. EMERY.—The first steam pipes I laid in the City of New York were carried across the street to the office of the company in substantially the way indicated. A 5-inch iron pipe was, however, used to form a conduit, being forced in from one vault by jack-screws, occasionally taking a scoop like a post auger to clear out the earth and sand that accumulated inside the pipe. Within the 5-inch pipe, two smaller pipes covered with felt were placed, to conduct the steam to, and bring back the return water from, the heating coils in our office building.

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468.
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THE USE OF ASPHALTUM IN BUILDING SEA WALLS.

By W. C. AMBROSE, M. Am. Soc. C. E.

WITH DISCUSSION.

The Ventura Division of the Southern Pacific Railroad is built for several miles along the bluffs facing the Pacific Ocean. The material of these bluffs is sand and gravel between strata of soft rock soluble in water; and though the violence of the waves is moderated by a group of islands about 22 miles off shore, at high water of spring tides with south-west gales they wash away the bank very rapidly, and protection for the road in some places was soon found necessary. The sea-shore at the foot of these bluffs is generally covered 2 or 3 feet deep with boulders and sand over the hard bed rock—hence the use of piling was impracticable. The rise and fall of tides, which would interfere very much with the work of building a concrete wall, as well as the high cost of labor, would make such a wall very expensive, so it was decided to try the use of asphaltum for a mortar to hold the boulders together, as a wall made of boulders alone had been easily knocked down by the waves.

At various points near this part of the road there are beds of material

known as bituminous rock, and asphaltum. The first contains fixed bitumen, 24.4 per cent., and ash, 75.6 per cent.; the ash consisting of silica, 46.8 per cent., carbonate of lime, 9.1 per cent., oxides of iron and alumina, 15.9 per cent., and other ingredients, 3.8 per cent. This material is much used in California in making pavements, and in coating piles to resist the teredo, which it does effectually. In order to liquefy it when heated, coal tar or crude oil must be added. About 200 feet of wall was built with this material, and it has stood perfectly for the last three years and prevented any washing away of the bank. After building this section of wall, the other material, known as asphaltum, was tried because it was cheaper. It liquefies without the addition of any flux, and when cooled it is not quite so hard but more elastic, and on the whole as good a cement as the other. It is often used for lining cisterns, and was used for 800 feet of this wall.

The wall was made 6 feet wide at the bottom (where it was in contact with the bed rock), 2 feet wide on top, and 9 feet high, the landward side, which was built close up against the cliff, being vertical. To economize asphaltum, only one half the wall, viz.: two feet backward from the seaward face, was cemented. The cost was $3.75 per cubic yard, which included everything except the old ties for fuel, and rail-transportation 28 miles for the asphaltum. In building this wall a layer of stones was placed, and the melted asphaltum poured over it so as to thoroughly fill all interstices and run down to adhere to the next layer of asphaltum. In warm weather the asphaltum becomes quite soft, but not liquid, and in this condition has little tensile strength, but the first spray from the waves hardens it just when necessary. The only part of the wall which failed was a short section where, to improve the alignment, it was built a little outside the base of bank, the space between being filled with sand. During a heavy storm, waves dashed over the top of the wall and saturated the sand, and the resulting increase in thrust from behind, pushed the wall over. This of course could have been avoided by making the wall so high that spray could not fly over it, or by increasing the width of base to resist pressure from the land side.

The writer thinks that when asphaltum can be had at a cost less than $10 a ton, this will be found a cheap sea wall. The stones on the beach, which because of their smallness and smoothness are of little or no use for ordinary rip-rap, can by this means be utilized, and are generally to be found in any required quantity on the spot.

DISCUSSION.

Mr. E. H. Wootton.—The question of using asphalt in masonry is not a new one; it has been tried for many years in Europe and there were some large blocks of asphaltic concrete placed at the mouth of the Gironde in 1865. I have made large blocks of asphaltic masonry here somewhat in the manner described by Mr. Ambrose; that is by taking the rock asphalt mastic pure, putting on a layer of stone, then another of asphalt, and then stone, and so on until the block is made. This solves simply and absolutely, the question of vibration in the matter of machinery foundations. Rock asphalt in large masses will not soften under any temperature. I have used it in this city in that way; the foundations of the two Edison 150 horse-power engines and eight dynamos, of the American Museum of Natural History, are of asphaltic masonry.

About the California asphalt I know very little. I saw the other day a piece of it at Dearborn street, in Chicago, and did not like it for street pavements. It is said to do very well on the Pacific Coast. I do not think there is the slightest question as to the desirability of the use of asphalt in sea walls; but the expense of using European rock asphalts would be very great. In small quantities it would cost about $50 a cubic meter, which might be prohibitive in any large sea walls. It might be made cheaper in large quantities, say $30. Whether the tars can be used to advantage in masonry, I do not know. In connection with French rock asphalts, I know they cannot; I should like very much to see true rock asphaltic masonry tried here on a large scale; of course water could not in any way affect asphalts, nor, in large masses, could heat. If not properly made it will soften under intense heat, but otherwise it will not.

The Secretary.—The point that occurs to very many is that there might be many points where ordinary coal tar would be a very useful material for cementing walls. I think Mr. Wootton hinted at that in his remarks. Of course, we know that coal tar will not last very long, but it is a cheaper material and might be used very effectively in some places.

The Chair, A. Fteley, Vice-President.—Does Mr. Wootton think coal tar could be advantageously used in such cases?

Mr. Wootton.—I know very little about the use of coal tar. The rock asphalts of Europe are bituminous limestones, containing about 10 per cent. of bitumen to 90 per cent. of lime (carbonate of lime). The asphalts, so called, used here, are different; the value of the hydrocarbon is a most important factor, and the sand mixture with Trindad bitumen I do not like as well as the limestone impregnated naturally. The use of European asphalts would certainly be much more expensive

than coal tar, Trindad, or California bitumens. With rock asphalt in masonry, vibration is impossible; it has been in use in Paris for such purposes about fifteen years; but this question of vibration seems to me to have little to do with the sea wall subject under discussion.

F. V. Greene, M. Am. Soc. C. E.—The objection to coal tar, for use in paving or any similar purpose, is its loss of strength by oxidation. The outside edge of it gradually wears away, the oil evaporates, and it loses its coherence. I think in large masses the coal tar would be comparatively durable, because the loss of the oils is from the outside, and is comparatively gradual. There have been a great many uses for coal tar in connection with paving, and whenever the tar has been kept from exposure to the atmosphere it has been successful; wherever used as a wearing surface, it has not.

There have been so many uses for tar developed in the last twenty years that the price has considerably increased. Refined tar is now worth about $17 to $18 a ton in this part of the country, and $18 to $20 in the interior. This California asphalt is much cheaper if they can get it. I think Mr. Wooton has covered almost all the cases for the use of asphalt masonry; almost all of them have been in Europe. The only case I know of in New York was an instance about two years ago. At the request of Tiffany & Company we built a foundation which was substantially a piece of asphaltic concrete, for a light trip-hammer in their factory on Prince street. For its construction I would refer to the following letter from J. W. Howard, C. E., who had charge of the work.

Captain F. V. Greene,
New York:

Dear Sir,—In answer to your request for information touching the Tiffany asphalt concrete foundation for their steam and drop-hammers, I send you the following data, from which you can select that which you may deem best. The asphaltic concrete block is 35 feet 8 inches long x 6 feet wide, x 4 feet deep. Upon it are placed seven large granite parallelopipedon blocks 2 feet thick. The seven blocks just cover the upper surface of the pier or asphalt concrete foundation. Each block just touches the next one. Each block is for the "anvil" of a separate "drop" or a steam hammer. There are four drop hammers, which strike a very sharp and following blow, and one steam hammer. The drop hammers are from, say, ½ to 1 ton each, and the steam hammers adjustable to perhaps above 3 tons. These hammers are used *ad libitum*, one or more at a time.

The asphalt concrete foundation is incased in a hard-pine box, held together by about 20 half-inch rods. The top of the granite capstones is level with the floor; thus the top of the asphalt concrete foundation is 2 feet below the floor, and the bottom is at 6 feet below the floor. The pier or foundation stands in a special room which was formed by the area or

yard of the building. The object in placing it there and in using asphaltic concrete, was to avoid the serious injury to the building, occasioned by the former foundations of the separate hammers, which occurred at several places in the basement; also to get rid of the jar so fatal to certain fine work on metal and glass, done in the upper portions of the building; also to make the place a pleasanter one to work and think in, for the employees. The foundation stands with its box free from the surrounding retaining wall, built for the purpose, 18 feet thick of brick. The cost of the "concrete," complete, was a very little less than $20 per cubic yard, but the cost of the wooden box and retaining wall being about $125, made the cost of the whole work, say, $24 per cubic yard (not including the granite or brick).

We tried the mixture which you indicated at first (with orders for me to change it until a proper mixture was obtained).

The first trial was with:

Asphaltic cement, 1 part		14½ per cent.
Sand, 2 parts	28¼ per cent.	
Broken stone (½-inch size), 4 parts	57¼ "	
		85½ per cent.
		100

This was too "rich," as it made a mastic. I tried in this mixture to get as close as possible to the consistency of the mixture I had seen used in France; and after using one load of it, we found the right mixture to be the following: Asphaltic cement, 9 to 8 per cent.; sand, 39 to 40 per cent.; stone, 52 per cent. A little limestone dust was used to secure a "dry" mixture which would retain its form at the average temperature of the place where the foundation was placed.

The mixture used as a final result was:

Asphaltic cement,	70 pounds	8½ per cent.
Limestone dust,	50 "	6½ "
Sand,	300 "	36 "
Crushed limestone,	400 "	49 "
Total,	820 "	100 "

This was laid up in 4-inch layers and tamped. We could not properly compress 6-inch layers.

Yours sincerely,

J W. HOWARD.

The CHAIR.—When you speak of tar as being successfully used when not exposed to the atmosphere, what do you mean?

Captain GREENE.—The bitumen foundations for pavements have been very successful. The work on the Manhattan Bridge was made of hydraulic concrete and granite blocks, making a double thickness of 17 inches.

Mr. THEODORE COOPER, M. Am. Soc. C. E.—I do not question the great benefit of asphaltic concrete foundations for machinery or for similar purposes, but I think the article described in the paper could hardly be classed as asphaltic concrete. It was, as I understand the paper, rock or boulders bound together with asphaltic cement to form a wall. The purpose of this wall was to resist the action of the sea in cutting away the embankment. The action of the sea upon a wall of that kind can only be of two kinds; if the wall remains a monolith the sea can overturn it or displace it as a mass; the other action of the sea is to disintegrate the wall. A wall formed of round boulders would be disintegrated very rapidly by the action of the sea, if cemented together with any of our ordinary mortars. Now, instead of using an easily broken mortar, which a Portland cement would be under the impact of a wave striking each joint, the author has used a plastic mortar, which is not acted on in that way. In this case it was an asphaltic mortar. The asphalt did not make the wall as a whole any stronger than Portland cement would have done; but I am satisfied that the reason he could not make a wall to stand with anything but plastic cement, was the disintegration of the cement mortar joints by the action of the sea.

EDWARD P. NORTH, M. Am. Soc. C. E.—The idea just touched upon by Mr. Wootton might, I think, receive further development; that is, the varying tenacity of different bitumens. There is a great deal of difference in the various qualities of bitumens; that from Trinidad is one of the most plastic of all. Those from Venezuela, Cuba, and Mexico, have in general less plasticity. The bituminous sand rocks found in California are all said to differ in quality; that used for street paving at San Diego, Mr. Schuyler, Member of the Society, writes to me, has its wearing qualities improved by the addition of from 10 to 15 per cent. of carbonate of lime, and must be about as soft as "refined Trinidad."

Specimens of sand rock from Kentucky, seem to be impregnated with a bitumen which is decidedly harder than that obtained from Trinidad, a circumstance which may or may not make it a better wearing material. In the European asphalts the lime rock is in most cases impregnated with a plastic bitumen, and in some the bitumen is so plastic and lacking in tenacity that it is impossible to use the asphalt in compressed work, for pavements, though such asphalts may make very good mastics.

I do not know that any one, before Mr. Wootton, has called attention to the variations in the quality of bitumens from different localities, or pointed out the fact that all bitumens are not equally available.

A. J. FRITH, M. Am. Soc. C. E.—Quite lately I heard of an instance which may be of interest in connection with this question of the use of

asphaltic concrete as a foundation for engines. My information is entirely hearsay. It seems that there were two establishments, in one of which there were a number of trip-hammers used, and in the other there was carried on a certain amount of engraving. The engraving concern complained that the jar from the trip-hammers interfered with their work, and for a long time it was considered that it would be necessary for the trip-hammer establishment to move away. However, the difficulty was gotten over by the use of asphaltic concrete as a foundation for the trip-hammers. This was entirely successful; and after it had been put in, there was no annoyance from the jar.

Captain F. V. GREENE.—I think the gentleman refers to a well-known case in Paris. Mr. Wootton can give us information about it. I do not think it was trip-hammers that were in use, but very heavy machinery in one house, and the engraver in the other.

Mr. WOOTTON.—It was at the Seyssel works. In the works there we have a crusher, and there was an engraver in glass who lived near by, who obtained an injunction restraining us from the use of our crusher. It was then decided that this asphaltic concrete might remedy the trouble. We put the crusher on the asphaltic masonry, and there is now not the slightest noise. The matter of the trip-hammers, I think, occurred at other works where the rock as it comes from the mine is crushed and ground, and the introduction of asphalt masonry was successful in the same way; those are the two cases, I think. In the case of the Seyssel works the change was made in 1878, and there has been no complaint since.

Mr. AMBROSE (closing the discussion) writes: Messrs. Wootton and Cooper have well explained an advantage possessed by asphalt over concrete in its plasticity and want of vibration under a blow. Another decided advantage in California is its comparative cheapness, as nearly all the best cement here comes from England.

Mr. Arthur Brown, Superintendent of Bridges and Buildings for the Southern Pacific Company used asphalt in building the foundations of the mansions belonging to Senator Stanford, the late Chas. Crocker, and the late Mark Hopkins, on what is generally known as Nob Hill, in San Francisco, and he tells me he found it very effective in preventing moisture of the soil from getting into the walls, as it is thoroughly non-absorbent of water.

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(Vol. XXIV.—March, 1891.)

A COFFER DAM OR CAISSON WITHOUT TIMBER OR IRON IN ITS CONSTRUCTION.

By Robert L. Harris, M. Am. Soc. C. E.

WITH DISCUSSION.

During the winter of 1888-89 the New York and Northern Railway Company determined to replace the iron bridge crossing Croton Lake with a heavier structure, one more in accordance with modern standards, to carry the rolling loads of the present day, and the writer was called upon to attend to the matter.

The masonry work in connection therewith developed what all may wish was a peculiar state of affairs, to the extent that what appeared a simple matter became one of anxiety, watchfulness and extreme care; its difficulties required special efforts, and were overcome by an original mode which may interest members of the American Society of Civil Engineers and the profession.

In order to make the matter clear, it is necessary to have a long preface to a short story.

The bridge existing in 1888 was a single track, wrought-iron deck structure of three spans of 150 feet each; total length, including cross-

ings of iron towers, about 480 feet; depth of trusses, center to center, 24 feet; width from center to center of trusses, 13 feet. These spans rested upon skeleton rolled-iron towers, 41 feet 7 inches high, each consisting of four columns properly tied and braced (24 feet 3 inches x 16 feet 8 inches between centers of base plates). The base plates rested upon granite blocks 12 inches thick and about 6 x 5½ feet in area, at the corners of bases of masonry, so called, 32 x 22 feet in area, about 7 feet thick, built upon cribs 47 x 35 feet, with nine compartments filled with stone. The cribs are represented on an original drawing as composed of 4-inch plank, laid cob-fashion, gained and bolted together; and around the cribs had been placed some rip-rap. The depth of water at the southerly crib is about 18 feet, at the northerly crib about 28 feet. The cribs and masonry bases were built about the year 1869 by the New York, Boston and Montreal Railroad Company, which company failed just before an iron bridge was to have been erected there. In the year 1879 the deck bridge mentioned was erected by Mr. A. P. Boller, M. Am. Soc. C. E., and did good service until its removal in 1889.

The masonry did not awaken suspicion upon preliminary examination, especially as it was old masonry, fully pointed (but some stones "quakered"), upon crib foundations that had been in place under water twenty years. It was therefore judged that all which would be necessary would be to add more rip-rap outside the cribs, and build piers of masonry within the skeleton towers upon the old masonry bases, increasing the lengths of spans to conform therewith. The weight upon the bed-plates of the skeleton towers at tops of stone bases had been over 17 tons per square foot; the weight of the proposed structure and its extreme load applied within the area of the skeleton towers at top of the bases would be under 3 tons per square foot, which by good arrangement, and including weight of base, could be delivered at the crib at less than 2½ tons per square foot.

As is usual in railway work, when anything is wanted, it is essential to have it quickly. Proper measurements were made, designs prepared, and contracts let for three heavy iron spans, and for two masonry piers upon the old masonry bases.

On the first day that workmen appeared (in February, 1889), holes were ordered drilled through the masonry bases at various designated points, with instructions to drill at least 6 feet, for the purposes of

thorough examination and of filling any possible voids with grout. The covering stones were large, well-bonded and apparently good. A gang of drillers began in the morning of a very cold day, and our painful surprise may be conjectured when these men were found at the blacksmith's fire in about an hour, and reported that the first hole, 2 inches in diameter, was completed! "We want the hole 6 feet deep at least." "It is down as far as our drills will go; we drilled 8 or 10 inches through the stone, then the drill went nearly of itself much of the rest of the way, except when bound for a few minutes." Other holes were tried with similar results. Some of the covering stones were then racked off, and I hope never again to see such rascally work where solidity is expected. The thin roof and sides were but a shell, enclosing large and small stones, boulders, posts, sticks, dirt, some sand, but no cement; even the joints of cover and wall stones had barrel staves and pieces of wood so placed as to prevent mortar from working into the main base. It was a loose mass, as though stone-boats and dirt-carts had been promiscuously used to "dump" in anything that would fill up.

My agreement, and also the contract of the masons, Messrs. Hodge & Miner, was only from above these masonry (?) bases. My inclinations were to abandon the work, but the president of the railway was absent at the West. At this time a friendly act was performed by a brother engineer whom I then slightly knew. A friend told me that Mr. A. P. Boller, M. Am. Soc. C. E., would like to see me; upon promptly visiting him, he unreservedly told me of his experience in 1879 at the same place, and handed me a copy of the *Transactions* Am. Soc. C. E., for April, 1882—very interesting reading to me at such a time!—and in which he related the ingenious manner in which he surmounted a difficulty that was presented to him.

The following quotation may be more agreeable to my audience:

"Before closing this brief account of a temporary construction, the disclosures of these old piers is a story worth telling, and of all deliberate, studied, cold-blooded frauds, those piers are entitled to the highest rank, and should consign to infamy all parties concerned in their creation. They were nothing but the merest veneer of stones set up on edge, with no cement detectable internally, and filled up with sand, stones and rubbish, an occasional barrel-head, and a plentiful supply of engineers' stakes, to 'level up with.' Many of the coping

stones were actually cut cross-grained, and no expense was apparently spared in doing anything wrong. Such instances of cold-blooded criminality almost restore any waning faith one may have in a hot immortality."

At the close of our interview he told me I could rely on the masonry corners, which he had rebuilt upward from the crib.

An entirely new phase of affairs had presented itself. It was decided, however, concurrently with the president, a member of this society, as the iron spans were now being built, and as the corner compartments of the cribs had carried the old weights so many years, to continue on the general plan, and begin the new work from near the crib, it being judged that a distribution of the increased weight over so large an area of the crib as possible would be sufficient.

The first thing necessary was to re-enforce the cribs for the changed application and increase of the weights to be borne. A mass of rip-rap having a berme of 7 to 10 feet at the top of the crib and a slope of one and a quarter to one, was placed around each crib.

Time had shown that Mr. Boller and Mr. Sebastian Wimmer, M. Am. Soc. C. E., were right in considering the corner compartments of the cribs sufficient for their purpose; they however, had the advantage of a summer season of very low water for their construction, while with us it was winter and early spring, the water icy cold, and Croton Lake at an ordinary level, with prospect of higher water. The Chief Engineer of the Croton Aqueduct informed me that the lake could not be lowered by reason of the scant water supply of New York City, nor would it be materially lower during the summer, which proved to be the case. The tops of the cribs were about 7 feet below the top of the bases, or only about 5 feet below water, just sufficient to require diving appliances or a coffer dam or caisson of some kind, to remove the interiors of the bases with extreme care. We removed all of the middle that we dared, by hand, chains, and grapples, but the water was too muddy to permit of careful work at the sides, ends or corners. The bottom of the lake was irregular and with many boulders; the old rip-rap, though scant, was spread out, and we had been obliged to place the new rip-rap before interfering with the bases.

Various expedients were considered and rejected; such as forcing sheet-piling through the rip-rap, covering the entire surface of the rip-rap with tarpaulin, etc. Upon reflection a plausible resource presented

itself, which further thought convinced me was feasible, and this seemed *the* place to try the experiment. We wanted a tight bottom at any level below the top of the crib, and tight sides thence to the water surface. The idea was to use the materials that were in place, and make a caisson therein without disturbance, by *cementing*, for the floor of the caisson, a portion of the loose mass of irregular stone-filling in the crib at any level below the top of the crib; and for walls, to cement from thence to the water surface, or as high as necessary to make good connection with the shell; this could then be pumped out, the interior carefully excavated to the crib, and the space filled with concrete rammed in layers to the top of the old shell. I spoke with several engineering and contracting friends on the subject. None had ever seen it done, only one (a Canadian contractor) expressed any confidence in the success of the trial.

The track upon the bridge was over 75 feet above the crib, and grout could be mixed upon the track over the crib and delivered directly through a hopper, pipe and nozzle; this was done, but the plan was soon changed to pumping in the grout immediately at the base. Holes were pushed and worked among the stones until a few feet below the top of the crib; these were held open until required, by crowbars, pipes, poles, etc. A long nozzle of 1½-inch iron pipe, connected to the discharge pipe of a No. 2 Douglas hand force-pump, was inserted in one of these holes to its bottom, water was rapidly pumped through for a few minutes, then the suction hose was suddenly transferred to a reservoir of grout, composed of Alsen Portland cement and fine sharp sand, in equal parts, mixed immediately before use; a small quantity only of the grout was slowly forced through, and the nozzle was then withdrawn but the hole maintained, and the same operation was proceeded with at other holes, seldom returning to any hole on the same day; my belief being, that in quiet water the cement would accrete on the surface of irregular stones at and below the level of injection, and that by consecutive slight accretions at proper intervals of time the voids between them would be filled.

I had tried an Edwards centrifugal steam-pump of 6-inch discharge to free from water the excavation made by the men who were working in rubber clothing, but with no avail; the immense sieve had too many and too coarse meshes. After repeating the above-mentioned operations for many days, with trials of the 6-inch steam-pump once in a while, ap-

parently with no success, I was on the point of abandoning the idea, of believing others' opinions in preference to my own judgment, when upon a Monday morning trial, after a quiet setting of thirty-six hours, the steam-pump, to my satisfaction, lowered the water a few inches; this assured me of success, and after patient continuance of grout injections a few days more, we pumped the space dry in a few minutes. We then proceeded with the excavation to the crib with so little water that at times a single man at the hand pump kept it free, and finally succeeded in putting in very rich béton, composed of Alsen cement 1, coarse sharp sand 1, broken rock 4, in solidly rammed layers of 9 inches thickness. During the excavation we found, at 6 feet away from the nearest nozzle holes, sharp-edged stones upon whose acute angles there were accretions of cement over ½ inch thick.

I had made a cemented caisson or coffer dam, in water, at a short depth below the top of the crib, using the loose stones there in place; and it is well to state that close observation during the operations failed to show loss of cement into the lake through the outside of the rip-rap; this is accounted for by the care exercised in forcing slowly but a little grout at a time at any one hole, and in giving it time to accrete upon the near rocks before another charge was applied.

We had obtained such success at the one pier in 18 feet depth of water that we adopted the plan (improved) at the other pier in 28 feet of water without serious trouble, and a heavy load of anxiety was lifted when solidly rammed Portland cement concrete filled these bases to the height of the walls of mere shell of the old "masonry" (?) bases, for, during all the time, trains were running regularly, though at low speed, over the spans resting on the iron legs supported by the four almost isolated corners of masonry.

Upon the concrete filling were reared the new piers, a little over 40 feet in height, the bases of which were about 22 feet 10 inches x 15 feet 4 inches, each narrowing at 8½ feet to a shaft whose base is 20 feet 7 inches x 9 feet 3 inches, and the top under coping 18 x 6 feet 9 inches, surmounted by coping 19 x 7 feet 6 inches, 18 inches thick. These support three deck spans of 156 feet 9 inches, center to center; depth of trusses, center to center, 25 feet 4 inches (total height from base of bed plate to base of rail, 27 feet 11 inches). The trusses are 13 feet between centers. These spans were designed by Theodore Cooper, M. Am. Soc. C. E., and were manufactured and erected by the Passaic Rolling Mill Company, of Paterson, N. J.

The process can be successfully used with rip-rap or rubble, and can be applied also to coarse gravel, gravel, sand, and even quicksand by the use of proper precautions. It affords a simple and convenient mode of making coffer dams, caissons, breakwaters, shore protections, etc., using largely the materials at hand or in place, instead of cumbersome structures for which all the material must be transported; especially is it useful in enlarging, repairing and strengthening sub-aqueous structures, while it may also be used in solidifying some kinds of materials for subterraneous structures, as tunnels, shafts, etc., and the enlarging of bases for foundations upon unstable materials.

In conclusion, I wish to emphasize the fact that this was not a work of choice; but necessity compelled the use of the old foundations, and it was required to accept the conditions as found, and to do the best possible with them and under the circumstances.

DISCUSSION.

Charles Macdonald, M. Am. Soc. C. E.—It would appear that the work described by the author, and illustrated upon the screen, is the familiar experience of a masonry pier founded upon broken stone enclosed in a timber crib, partially surrounded with rip-rap. Foundations of this kind have been successfully used in many parts of this country (where there was no tendency to scour), without involving the expense of injecting cement mortar through the upper layers, and it is difficult to understand the object of departing from previous practice in the present case. The late Mr. Fred Mercur constructed several piers in 40 feet of water on the Lehigh River, by sinking cribs and filling with broken stone, upon which masonry was started a short distance below water level. In one case the crib in sinking came in contact with an old canal boat which lay diagonally across the axis of the pier. Time was short, and to remove the canal boat would have been a very serious matter, so it was decided to dump broken stone through the crib and around the outside until a suitable bearing for the masonry was reached. In the construction of all these piers there was, no doubt, more or less settlement, as the weight of masonry was added, but all necessary compensation was provided in the finishing courses. I adopted this method, although in much shallower water, in founding three piers in the Schuylkill River. Every new course of masonry

Note.—It is proper to state that the mode described in this paper was patented in 1890.

R. L. H.

Fig 1.

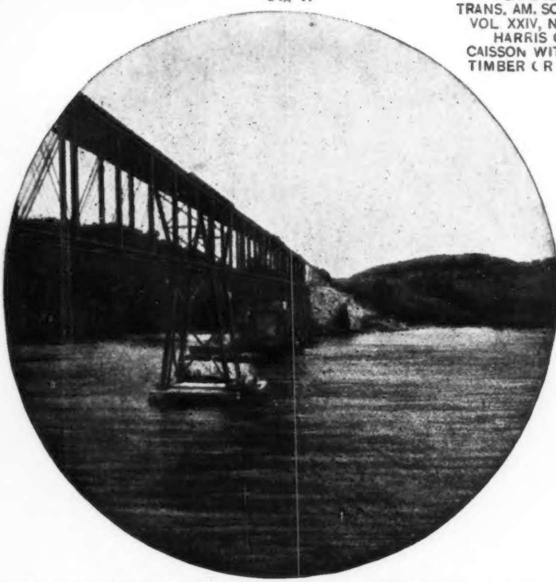

Figure 1 is a view of Croton Lake Bridge upon iron towers, as it was previous to 1889, and before the northerly pier was begun.

Fig. 2.

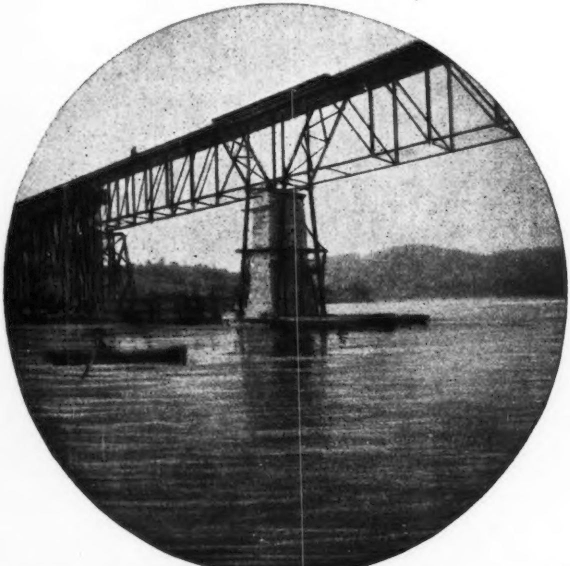

Figure 2 is a view of the old spans still on iron towers, but both masonry piers are built.

Fig. 3.

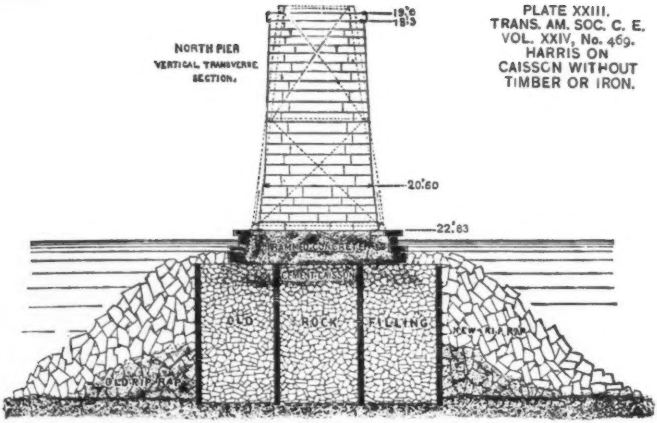

PLATE XXIII.
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HARRIS ON
CAISSON WITHOUT
TIMBER OR IRON.

Figure 3 is a vertical transverse section of the northerly pier.

Fig. 4.

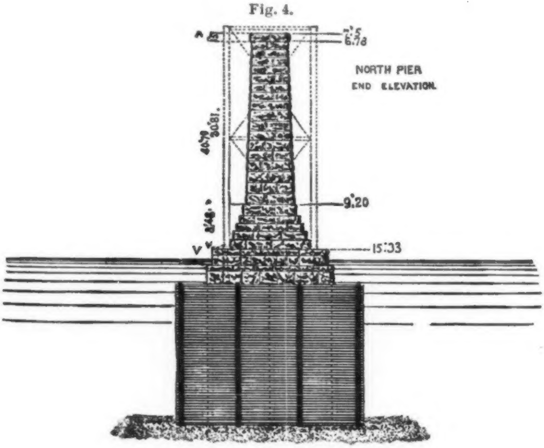
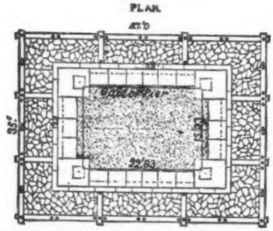


Fig. 5.

PLAN



Figures 4 and 5 are respectively an end elveation and a plan of the northerly pier.

Fig. 6.

PLATE XXIV.
TRANS. AM. SOC. C. E.
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HARRIS ON
CAISSON WITHOUT
TIMBER OR IRON.

Figure 6 is a view of the completed northerly pier with two of the new spans resting thereon, and a portion of the false work.

Fig. 7.

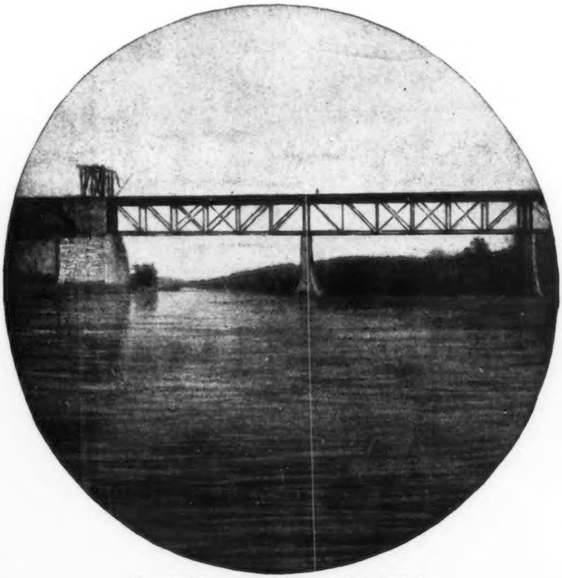

Figure 7 is a view of the completed work.

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caused a slight settlement, sometimes canting the pier out of line, but by paying proper attention to the levels from day to day the work was finished up substantially as required, and there has never been any disturbance since. I do not wish to be understood as advocating broken stone foundations in opposition to rock in place, or other equally suitable foundation. The instances above mentioned are given merely for the purpose of showing that such foundations may be relied upon under certain circumstances, if properly handled, and that the injection of cement mortar through the upper portion of the broken stone cannot, from the nature of the case, alter or improve the character of the support beneath.

J. Foster Flagg, M. Am. Soc. C. E.—Mr. Harris has clearly described how the bottom of his caisson was made tight, by the injection of grout between the interstices of the loose rock, but I do not understand how he formed the walls of his caisson. Was the masonry of the outer skin of the pier laid well enough to answer this purpose and prevent the passage of water, or was the same process pursued for making the walls water-tight as for the bottom? If the existing masonry was depended upon for this purpose, how thick was it necessary to leave it in excavating the caisson for the new concrete foundation?

T. C. Clarke, M. Am. Soc. C. E.—How deep did you go under the water?

R. L. Harris, M. Am. Soc. C. E.—I wanted to get to the crib, the top of which was only about 5 feet below ordinary water surface, while the water was about 28 feet deep. The means I adopted to make a cement floor for the caisson was to force cement through pipes which reached a few feet below the top of the crib.

Mr. Clarke.—You actually got under the water 5 feet?

Mr. Harris.—The top of my floor was about 5 feet under water, but my operations of floor-making were mostly below this depth. I wanted to remove the poor material down to the crib. In reply to Mr. Flagg's question: The top of my newly-constructed floor was nearly at the top of the crib; the space between the floor and the shell of the old base was filled with injected grout, forming walls; we used sand bags and cement bags to aid in making the joint, and also in making tight the shell composed of the old stones.

Mr. Clarke.—How thick were they?

Mr. Harris.—The old walls varied in thickness from 12 to 24 inches.

The Chair (A. Fteley, Vice-President Am. Soc. C. E).—Do I understand that on the gravel bottom of the lake you have a mass of rip-rap or dry stone without any cement, and that you have formed on the top of that pile of stone the capping of cemented masonry that you are speaking of? The ultimate base of the bridge is this capping, I understand.

Mr. Clarke.—This question of building on broken stone is a very

interesting one. My experience has been that, providing you get your foundation large enough and reduce the pressure per square foot sufficiently, there is no difficulty in doing it. The great difficulty is when we have a foundation in which the supporting power varies, where one part of it is not as hard as the other. Mr. Macdonald gave an illustration of building over an old canal boat; I once had to do the same thing. In one of the piers of the Girard Avenue Bridge at Philadelphia the foundation stands on an old canal boat. The piers are about 120 feet long and 20 feet wide at base, 10 wide on the top and 45 high; they rest upon cribs which are filled with concrete. The bed of the river is rock and was covered with 3 or 4 feet of material which had to be removed by dredge. When we began to dredge we found something in the way; we dredged off the clay, etc., so that the divers could get at it, and we found that there was an old canal boat sunk there, loaded, as the divers discovered, with pig-iron, and this boat lay diagonally across where I wanted to build my foundation. These cribs were about 130 feet long by 30 feet wide. I did not exactly know what to do, but as I had to do something, I designed my crib in such a way that it should stand right over this canal boat. I came to the conclusion if it was loaded with pig-iron it must have come to its bearings; so I dredged out each side and made a sort of saddle, and built the pier upon it, and there never was the slightest indication of settling.

The Chair.—In view of what has been said by Mr. Macdonald and Mr. Clarke, have you found in your practice, Mr. Harris, in erecting your pier on this foundation, any settlement, one way or the other, or have you observed the levels at all?

Mr. Harris.—There has been nothing extensive; of course, we naturally expect some settlement in work of the kind. I have had nothing to do with it for the past few months, but think it is all right. (It was built in 1889.) During the erection of my work there was some settlement, but not enough to result in trouble.

Mr. Macdonald.—The settlement I referred to occurred from day to day and was leveled up by the masons each morning when they came on and found that a course was not exactly level.

The Chair.—You speak of the difference of alignment as about 8 inches; I should say that that required considerable care in order to have straight arises.

A Member.—There was a decided difference in the two cases; in Mr. Macdonald's case the stone was thrown in just before building the pier; in Mr. Harris's case, they had been thrown in a long time before and had had time to settle, that would make a much better foundation.

John N. Ostrom, M. Am. Soc. C. E.—In reference to grouting in loose stone, I have had a little experience. A few years ago I was building some bridges in Texas and the Indian Territory. In several of the bridges the masonry was to be located on a concrete foundation. I

found in one case, after getting on the ground, that a young engineer who was in charge of the work, not knowing exactly how to make his concrete and not mixing it in the ordinary way, had made his excavation, filled it up with the proper amount of broken stone and then made a grout and ran it through. He had used about sixty barrels of cement in one small pier; the pier on the face of it, was about 10 x 30 feet. In that case the grout had permeated to the very bottom. There was a great deal more cement used than necessary. I do not understand in Mr. Harris's case why the grout did not go deeper, unless the broken stone was filled up with silt. I think if it had been put in when the broken stone was first deposited, and before the silt had permeated the pile, and if he had tried to form a thin caisson at the very top, he would have failed to the extent that he would have had to fill that whole mass of broken stone. I cannot understand it otherwise; I know in my case they used sixty barrels of cement in one small pier. I would ask how much cement was used? The question of cost, of filling a whole pier to the very bottom, would have been very serious.

George R. Hardy, M. Am. Soc. C. E.—As I understand it, there was considerable expense incurred for removing the central portion of the old work after the floor was made; and it occurs to me to ask whether you could not have continued the work, and concreted the entire mass without excavating inside of the cement coffer dam, having once established a box sufficiently water-tight to prevent the cement or concrete from escaping.

Mr. Harris.—The material I wanted above the crib was thoroughly rammed Portland béton; engineers know that can be depended upon. We could have a larger bearing-surface down in the crib by reason of the flowing of the cement to a short distance, thus resulting in a tight floor of considerable area. I obtained not only an extended floor, but also cemented sides, to my caisson, to carry the rammed béton that was introduced.

Charles E. Emery, M. Am. Soc. C. E.—While it appears that bridge-builders have different methods of arriving at a result, I think that the method adopted shows great originality and one which can be employed in other cases, for instance in tunnel work, in enlarging foundations, etc. Very great credit is due Mr. Harris for successfully carrying out a novel engineering work, even if it be not done in the same way that those who have used cribs for so many years would have done it. I have been very much interested and can see quite a number of applications. The method of grouting employed in the recent tunnel under the Thames for the South London Railway is familiar, but grouting in this case accomplished another purpose and made a coffer dam. The application of the grout in small quantities so as to form gradual accretions like those on foreign substances in mineral springs, is very interesting, and it is probable that the success in making a tight floor at the top of a pile of loose stone, is entirely due to the special method.

CHARLES B. BRUSH, M. Am. Soc. C. E.—I understand that Mr. Bogart is familiar with the rip-raps at Fortress Monroe; I would like very much to hear something about that construction.

JOHN BOGART, M. Am. Soc. C. E.—The only point in connection with the very interesting paper of Mr. Harris is the fact that rip-rap foundation will hold itself in remarkably good shape, even after a very great settlement. The stone fort on the rip-raps was commenced in the early part of the century—probably about 1830. The rip-raps are nothing but an artificial island of stone on a sandy shoal which seemed to be very solid. The shoal was from 70 to 16 feet deep, and the island was made of broken stone of large size, brought from Maine and from the Richmond quarries, and thrown overboard from the vessels upon this rip-rap island. In 1861, this former fort which had been built up one tier of casemates was being loaded by order of the then Chief Engineer with a very large amount of granite, because it had shown some signs of settlement. The whole island settled, I should say something like 8 feet, and rather regularly. A new granite fort was commenced and was built during the years 1861–66, and no more settlement was observed up to the time that I left there in 1866, that was after five years; the island seemed to have reached a solid foundation. There was a layer of sand directly beneath the rip-rap, I do not know how thick, and there seemed to be a layer of some soft material under the sand which was pushed out into the sea.

MR. BRUSH.—Did the rip-rap stand outside the fort?

MR. BOGART.—Yes, all round outside the fort; a berme of 20 feet, and then it takes a slope of perhaps 1½ to 1 feet, running down in some places to 70 feet of water.

MR. BRUSH.—What was the object of building that fort?

MR. BOGART.—The object was in connection with Fort Monroe, which commands the channel to Norfolk and to Richmond.

J. FOSTER FLAGG, M. Am. Soc. C. E.—Is not Fort Carroll, in Baltimore Harbor, built in the same way?

MR. BOGART.—It is built on an island, and there was some settlement but nothing like this.

E. P. NORTH, M. Am. Soc. C. E.—Is there any one here who knows how much loose rock, thrown in for foundation, will settle, that is, neglecting the settlement of the material it is resting on. I have never seen any statement that rock itself would settle more than about 4 or 5 per cent. of its thickness, when it is thrown in for foundation.

MR. EMERY.—Does not the old Croton Aqueduct, in some sense, answer that question? My recollection is it was built with retaining walls and filled in with dry stone.

MR. BOGART.—I am very sure that in filling in with loose rock above water, with a very slight adjustment of the rock as it goes in, the settlement is very slight; I know from experience not to exceed 3 or 4 per cent.

The CHAIR.—Engineers who are building railroads have on many occasions to make use of rock taken from cuts; if there is anybody here who has any data in regard to that matter it would be a good answer to Mr. North's question. I understand that railroad engineers expect a certain amount of settlement.

Another question has been asked by Mr. Emery which I might answer, so far as my knowledge goes, of old matters that were not under my direction. It is a fact that the old Croton Aqueduct, which has been for so many years the main water supply of New York, wherever it is placed on high embankments, is built on a high wall made of dry stone, and the greatest trouble the engineers have experienced has come from that fact. Although those walls were built by placing the stones by hand, there is no question that the aqueduct has settled greatly, thus developing cracks; that water penetrating those cracks has reached the foundation, softened it and probably produced thereby a still greater settlement.

JAMES OWEN, M. Am. Soc. C. E.—Mr. Ashbel Welch stated that in making a rip-rap masonry wall 40 feet high, along a river bank, the settlement during construction was 4 inches.

Mr. HARRIS.—This discussion has turned in a way that I hoped it would not; perhaps we are discussing that "long preface" instead of the "short story;" we have been diverted from caissons and coffer dams to rip-rap and loose rock, and I would request members to discuss the subject of the evening. My paper is not in advocacy of rip-rap nor of broken rock foundations. I had hoped to listen to a discussion in regard to caissons and coffer dams, although what the gentlemen have said has proved very interesting. If you wish broken rock talk, perhaps one instance that has come under my observation in New Mexico will be of interest.

Within the past three weeks I have seen a rock-fill dam, 45 feet high, extreme length over 1,000 feet, its upper face made tight with earth. I looked at the outside of it; it was as dry as any masonry dam; it has not been finished over a year and a half. This was a case where the managers had sufficient confidence to build a broken rock dam, reported to have cost a couple of hundred thousand dollars, for very extensive irrigation works, and which would cause immense damage if it should give way.

WILLIAM E. WORTHEN, M. Am. Soc. C. E.—Under such conditions I should silt up the dam with sand.

Mr. HARRIS.—That is probably what really occurred.

Mr. NORTH.—If that dam was silted up with sand would it be as strong? Would not any water in the dam weaken it? Those rock dams are built tight on the upper side and perfectly open on the lower side, so that any water that does get in passes through it.

Mr. MACDONALD.—Might not that process of construction very well be applied to the Quaker Bridge dam?

CHARLES B. BRUSH, M. Am. Soc. C. E.—I understand that Mr. Bogart is familiar with the rip-raps at Fortress Monroe; I would like very much to hear something about that construction.

JOHN BOGART, M. Am. Soc. C. E.—The only point in connection with the very interesting paper of Mr. Harris is the fact that rip-rap foundation will hold itself in remarkably good shape, even after a very great settlement. The stone fort on the rip-raps was commenced in the early part of the century—probably about 1830. The rip-raps are nothing but an artificial island of stone on a sandy shoal which seemed to be very solid. The shoal was from 70 to 16 feet deep, and the island was made of broken stone of large size, brought from Maine and from the Richmond quarries, and thrown overboard from the vessels upon this rip-rap island. In 1861, this former fort which had been built up one tier of casemates was being loaded by order of the then Chief Engineer with a very large amount of granite, because it had shown some signs of settlement. The whole island settled, I should say something like 8 feet, and rather regularly. A new granite fort was commenced and was built during the years 1861–66, and no more settlement was observed up to the time that I left there in 1866, that was after five years; the island seemed to have reached a solid foundation. There was a layer of sand directly beneath the rip-rap, I do not know how thick, and there seemed to be a layer of some soft material under the sand which was pushed out into the sea.

Mr. BRUSH.—Did the rip-rap stand outside the fort?

Mr. BOGART.—Yes, all round outside the fort; a berme of 20 feet, and then it takes a slope of perhaps 1½ to 1 feet, running down in some places to 70 feet of water.

Mr. BRUSH.—What was the object of building that fort?

Mr. BOGART.—The object was in connection with Fort Monroe, which commands the channel to Norfolk and to Richmond.

J. FOSTER FLAGG, M. Am. Soc. C. E.—Is not Fort Carroll, in Baltimore Harbor, built in the same way?

Mr. BOGART.—It is built on an island, and there was some settlement but nothing like this.

E. P. NORTH, M. Am. Soc. C. E.—Is there any one here who knows how much loose rock, thrown in for foundation, will settle, that is, neglecting the settlement of the material it is resting on. I have never seen any statement that rock itself would settle more than about 4 or 5 per cent. of its thickness, when it is thrown in for foundation.

Mr. EMERY.—Does not the old Croton Aqueduct, in some sense, answer that question? My recollection is it was built with retaining walls and filled in with dry stone.

Mr. BOGART.—I am very sure that in filling in with loose rock above water, with a very slight adjustment of the rock as it goes in, the settlement is very slight; I know from experience not to exceed 3 or 4 per cent.

The CHAIR.—Engineers who are building railroads have on many occasions to make use of rock taken from cuts; if there is anybody here who has any data in regard to that matter it would be a good answer to Mr. North's question. I understand that railroad engineers expect a certain amount of settlement.

Another question has been asked by Mr. Emery which I might answer, so far as my knowledge goes, of old matters that were not under my direction. It is a fact that the old Croton Aqueduct, which has been for so many years the main water supply of New York, wherever it is placed on high embankments, is built on a high wall made of dry stone, and the greatest trouble the engineers have experienced has come from that fact. Although those walls were built by placing the stones by hand, there is no question that the aqueduct has settled greatly, thus developing cracks; that water penetrating those cracks has reached the foundation, softened it and probably produced thereby a still greater settlement.

JAMES OWEN, M. Am. Soc. C. E.—Mr. Ashbel Welch stated that in making a rip-rap masonry wall 40 feet high, along a river bank, the settlement during construction was 4 inches.

Mr. HARRIS.—This discussion has turned in a way that I hoped it would not; perhaps we are discussing that "long preface" instead of the "short story;" we have been diverted from caissons and coffer dams to rip-rap and loose rock, and I would request members to discuss the subject of the evening. My paper is not in advocacy of rip-rap nor of broken rock foundations. I had hoped to listen to a discussion in regard to caissons and coffer dams, although what the gentlemen have said has proved very interesting. If you wish broken rock talk, perhaps one instance that has come under my observation in New Mexico will be of interest.

Within the past three weeks I have seen a rock-fill dam, 45 feet high, extreme length over 1,000 feet, its upper face made tight with earth. I looked at the outside of it; it was as dry as any masonry dam; it has not been finished over a year and a half. This was a case where the managers had sufficient confidence to build a broken rock dam, reported to have cost a couple of hundred thousand dollars, for very extensive irrigation works, and which would cause immense damage if it should give way.

WILLIAM E. WORTHEN, M. Am. Soc. C. E.—Under such conditions I should silt up the dam with sand.

Mr. HARRIS.—That is probably what really occurred.

Mr. NORTH.—If that dam was silted up with sand would it be as strong? Would not any water in the dam weaken it? Those rock dams are built tight on the upper side and perfectly open on the lower side, so that any water that does get in passes through it.

Mr. MACDONALD.—Might not that process of construction very well be applied to the Quaker Bridge dam?

The CHAIR.—I will for obvious reasons ask somebody else to answer that question.

I see, Mr. Harris, that you have been trying to bring the audience back to your paper, and have succeeded in making another diversion. I will try to assist you, if I can, by asking a question. You have, in your conclusions said that you thought such a process as you have resorted to would be very useful in foundations under water or in sliding masses of gravel. This is a subject on which there is very little known, and I would ask whether any one present has, in his experience, ever injected grout into a mass of gravel, or a mass of stone, or into a medium supporting a structure of any kind, and whether in so doing he has produced a foundation better prepared to support a heavy weight?

CLEMENS HERSCHEL, M. Am. Soc. C. E.—My sympathies have been with Mr. Harris to a great extent in having given us a paper on the injection of cement into broken stone, in his case for the purpose of forming a coffer dam, but the process could also be used to solidify masonry, either under or above water. The audience having gone off into other channels, and you having brought the subject back to the injection of cement into masonry or broken stone, I will cite a few instances of such work that was done under my charge.

The masonry about the works at Holyoke, Mass., were built in 1848. Like Mr. Bogart at Fort Monroe, I was not there when they built them, but about forty years after, for some unaccountable reason, it began to come to pieces. The stones were very large rocks and, of course, on that account there was no danger, so far as stability was concerned. Being in constant use, there was no such thing as making the repairs in the ordinary way; but on the fourth of July there are two or three days in every year when the water is drawn off, and we concluded to try boring and drilling holes beforehand through this masonry, very close together. Advantage was taken of these two or three days to pour cement through such holes into the masonry, and attempt to stop these leaks. That seemed to be the only thing that could be done under the circumstances, and we concluded to attempt it. The various classes of masonry were treated in that way, holes being drilled through, some 15 or 16 feet deep.

Mr. CLARKE.—How large?

Mr. HERSCHEL.—About 2-inch holes. There are various kinds of masonry there, some large and some small stone, and some almost dry walls. We did this for two years; that is, it was only treated on two occasions, but the drilling occupied a very long time, and in most cases the success was very marked. Some walls that leaked like a sieve are now quite tight. This is a case of pouring cement somewhat similar to what Mr. Harris mentioned, only the masonry was a great deal more regular; it is another example of injecting cement in stone.

REUBEN SHIRREFFS, M. Am. Soc. C. E.—I can add another illustra-

tion of the same principle. Down on the James River there was a wooden bridge that was destroyed during the war. The piers were built of ordinary rough stone entirely dry. In course of time, some twenty-three or twenty-four years, I think, had elapsed before they were used again, the railroad company with whom I was at that time, undertook in conjunction with the town, to bridge the river with an iron bridge, and it was determined to use the old piers. We did it in much the same way as Mr. Herschel repaired his masonry. We pointed the outside joints very carefully for a height of about 5 feet perhaps, and when we could find a crack deep enough to insert an iron pipe we put it in and forced in the cement in that way. We had some repairing to do in some cases, but it worked admirably and the piers are solid, and it is hoped they will be for a good many years yet.

Mr. Harris.—Did you use a pump ?

Mr. Shirreffs.—No; we just used head. I do not remember now how much it took per cubic yard. In this connection I might cite the case of a coffer dam across the same river at Lynchburg, which I used in building a dam there. The rock bottom was completely bare; it was considerably laminated and there was no chance at all to hold an ordinary sheeting, so we built a crib of logs, filled it and sunk it with stone and then on the upper side we banked it with dirt and let the dirt be carried into the interstices of the stone; it made an admirable coffer dam.

Mr. Worthen.—A great many years ago I read of the French way of injecting under foundations; they drilled holes down and injected cement in that way. About 1845 I had to repair the foundations of a flume and did not want to dig it up; so I put holes along wherever it was unsound and made a syringe to inject the cement under the foundation. The pipe was a 6-inch pipe and went up about 3 feet high; that was bolted to the flume. I filled it with cement and then used a wooden follower in the pipe and rammed the grout down until it appeared at the next hole. The work has stood thoroughly well since.

In 1853 or 1854 we put a second track on the New Haven road at Westford. We had a draw pier and it was of very poor masonry. We drove piles outside of the pier and put in a stone wall laid in cement. The old wall was horrible, so I took it down as low as I could and put sand on the top and squirted in the cement. The pier is there to-day and doing good service. I think if you can once fairly silt up loose rock, it will be in most cases as durable with sand as with cement.

Mr. Harris.—In reply to Mr. Ostrom, I would say, that just before success was assured I began to fear that I might be obliged to fill the crib, or try some other plan. As a matter of special interest in this connection, an incident occurred immediately previous to the complete sealing of the floor, which indicated a great deal to me, but which generally would be of more value to naturalists than to engineers. A

sudden burst of water near the middle of the floor brought into the enclosure a lively eel, 1½ inches in diameter and nearly 2 feet long, which must have come from the outside through 20 to 25 feet of angular rip-rap and broken stone filling; its skin was not even scratched. The quantity of cement used was 101 and 134 barrels respectively for the two piers, mixed with equal bulks of sand. My caisson was a great deal cheaper than any other which could have been constructed.

In regard to the dam at Holyoke, I would ask Mr. Herschel whether the water was drawn down before the grout was put in?

Mr. HERSCHEL.—The work was not done on a dam, but in canals, and they were dry. The grout filling was cement and water, no sand. I mentioned it as being nearly a parallel case. I think yours is the only case I ever heard of where the grouting was done under water.

Mr. HARRIS.—We have now heard of grouting in various ways; all of these are good instances of ordinary modes of applying grout. In this very neighborhood, upon our new Croton Aqueduct, we have ingenious examples of grouting still more striking.

I will go beyond these, to grouting under water. Since writing this paper, I have read, in current technical literature, of the exceedingly interesting experiments and practice of Mr. Walter Robert Kinipple, M. Inst. C. E., as described in reports of his late lectures on "Subaqueous Foundations." It is said in these reports, that Mr. Vernon Harcourt's work, on "Harbors and Docks," 1885, states: "The lower courses of the superstructure being laid below low water, cannot be cemented together." Mr. Kinipple's experiments of 1883 and 1884 were apparently made by sinking a box in which small broken stones were placed, and then filling the remainder of the capacity of the box with grout; as for instance, at Aberdeen "A very thick grout * * * * was poured down the pipe in sufficient quantity to fill up the whole of the interstices." He subsequently put these experiments to handsome use in the building of heavy sea walls, and in each instance cited he had, or formed, a bottom, and he formed sides for the retention of grout, as per the following extract in regard to the Hermitage Breakwater, about 1887: "It" (a section of rubble or shingle) "was enclosed by bags of concrete on three of its sides and made cement tight all round." What I wished to draw out from the gentleman was: do they know of any case where cement grouting has been carried on, under water, without there being beforehand a confining bottom, or confining walls, or both? do they know of any case where use has been made of the plan which I adopted? a plan which, if I mistake not, differs esentially from, and goes beyond, the various modes of grouting which have been spoken of this evening. My process is based largely upon the principle of successive accretions.

My idea was doubtless suggested by reason of some lime incrustations at a spring where I camped over twenty years ago, and where twigs

became encased during a single night; which experience I recollected six years ago, and which then rather astonished a young and blooming saleswoman of curiosities at Manitou, Colo., who had labored bewitchingly a long time to impress upon myself and family that a thousand years were required to incrust to the thickness of $\frac{1}{16}$ of an inch.

In the work described in my paper, my belief was, and the result sustained it, that a thin scale or film would be made on the rocks at the first injection of the grout; at the second injection an additional thin scale would accrete, and so on; thus not requiring either bottom or sides to confine the cement. In digging out some rocks after I had partly made the floor, I found a stone, with acute angular planes, on the sharp edge of which over half an inch of cement had accreted; this interested me deeply.

My belief is that my mode is different from ordinary grouting, that it is new, and also is an application of the principle of accretion, of adding little by little, similarly to the processes of nature.

H. W. Brinckerhoff, M. Am. Soc. C. E.—Did your observation show that the accretion was usually greater upon the edges than upon the sides of the stones; as, if this were the case, it would tend to close the openings more rapidly than if uniformly distributed, and would thus materially contribute to the success of the operation?

Mr. Harris.—No, sir; I observed the most striking features. When I saw that edge, there followed instantly the thought, "I have it now."

Mr. Worthen.—How did you find the cement and sand; did they keep together?

Mr. Harris.—They kept together admirably; the accretion was formed of cement and sand both.

Mr. Clarke.—Did you have any trouble from the clogging of your pump?

Mr. Harris.—Yes, sir; I began the work with head alone; subsequently I used the pump. The pump would clog when using coarse sharp sand; I tried different qualities of sand and finally obtained a kind that would carry with the cement.

The Chair.—I have had some experience in grouting. If coarse sand is used, the specific gravity of the cement and sand is so different that they will not mix well together; but when a quality of sand can be procured too fine possibly for ordinary masonry, but which in fineness and general density is somewhat similar to cement proper, the mixture is satisfactory and the grout in place is generally found to be homegeneous.

On motion of Mr. North, a vote of thanks was tendered to Mr. Harris for his original and interesting paper.

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